Industrial Heat Pumps, Second Phase

IEA Heat Pump Programme Annex 48

Task 2: Headline

Prepared by
Japan National Team

Contents

1 Introduction

The legal text of Task 2 indicates "Structuring information on industrial heat pumps and preparation of guidelines. A heat pump data base to be used for structuring the information of Task 1 for each industry with best available technologies and best practices."

Based on the legal text, the following works are needed to be performed in Task 2.

- To develop multiple criteria to evaluate good practices investigated in Task 1
- To make scoring for good practices based on the multiple criteria
- To develop a decision-making method which can select the best practice of each industry from samples collected in Task 1
- To describe the detailed information on the best practices selected by the evaluation method
- To support further activities of R&D and policy required for the wide spread of industrial heat pumps

2 Evaluation Method

2.1 Criteria of evaluated items

There are many different samples in industry of good practice applications. There are also many different criteria to evaluate the best practice among good practices. The best practice needs to be selected from the samples of each industry.

To identify stakeholders' perspectives towards the best practices of industrial heat pumps, multiple criteria should be developed to solve complex problems of decision making based on the market potential of IHPs, technological advantages of IHPs, and effects of installation. The following items are selected as criteria for a substantial amount of reliable data among good practice samples in the matrix of Task 1.

- Market potential of IHPs
  1) Heat demands of industries
- Technology and system
  2) Heating/cooling capacity
  3) Supply temperature
  4) Low GWP working fluid
  5) Simultaneous heating/cooling system and skilful waste heat recovery system
- Effects of installation
  6) Energy saving
  7) CO_2 emission reduction
  8) Cost savings
  9) Additional effects

2.2 Industries selected for the evaluation

Good practices in the matrix of Task 1 should be investigated by the selected criteria. Industrial heat pumps have been installed in various kinds of industries. The following four industries are the dominant groups in the number of good practice samples investigated in Task 1.

2.2.1 Food / agriculture / fishery

The number of good practices in this industry is dominant at 46% of the total practices. However, the market potential is estimated to be small, only 4% of the heat demand investigated from auto steam generation in Japan. In the industry, heat pumps are applied for heating, cooling, freezing, heat retaining of food materials, cleaning, sterilization, drying, and distillation. The level of supply temperature mainly ranges from minus 30 °C to 80 °C and holds over 120 °C in the drying and distillation fields. The thermal capacity of heat pumps is rather small or medium. Most of the samples in the industry use simultaneous heating/cooling systems which are able to attain higher efficiency.

2.2.2 Machinery / electronics

The number of good practices in the industry is large at 33% of the total practices. However, the market potential is also estimated to be small like the food/agriculture/fishery industry at only 2% of the heat demand. It is applied for heating, cleaning, drying, processing before painting, and heating for gilding, or pure water tanks. The temperature is higher than in the food industry ranging from 50 °C to 150 °C. Installed thermal capacity is ranged to be wide, small, and medium size as well as megawatt class.

2.2.3 Paper products

The market potential of paper products is estimated to be large at 26% of the heat demand investigated from auto steam generation in Japan. However, the number of good practices is limited at only 3% of the total practices owing to a large number of cogeneration systems installed. Heat pumps are applied for melting and drying for the adhesion or printing process of paper and film. The level of temperature is rather high ranging from 60 °C to 150 °C, and the size of thermal capacity is large.

2.2.4 Chemicals

Heating demand is the most predominant, occupying 43% of auto steam generation. The number of good practices is rather small at 13% of the total practices. Heat pumps are used for chemical processes of drying, concentration, distillation, and melting. The temperature level is the highest above 150 °C. Development of high temperature heat pumps as well as large size thermal capacity is needed to increase the market share.

2.3 Superiority of criteria items

We decided a level of superiority evaluated by the relative merit of criteria. It is judged by the distribution of item data on all samples of good practices. The superiority level is categorized into three different ranges of high, medium, and low. An item is given three points at the high level, two points at the medium level, and one point at the low level. An item with no available data is accounted to have zero points because of the lack of data. The level and superiority score are indicated by the data distribution of criteria items in Table 1-1.

Market potential is evaluated by the statistics data of heat demand for each industry in Japan as shown in Table 1-2.

Table 1-1: Scores evaluated for criteria items

Items		Superiority		
		High (3 points)	**Medium (2 points)**	**Low (1 point)**
Market potential (Heat demand of auto steam generation)		Large (over 100,000TJ)	Moderate (10,000～100,000TJ)	Small (below 10,000TJ)
Technology & system	**Heating/cooling capacity**	Over 1 MW	100 kW－1 MW	Less 100 kW
	Supply temperature	Over 90 °C	60‑90 °C	Less 60 °C
	Low GWP working fluid	Non Freon	Low GWP	High GWP
	Simultaneous heating / cooling or waste heat recovery	Both applications	One application	No application
Effects	**Energy saving**	Over 60%	30–60%	Less 30%
	CO2 emission reduction	Over 70%	30–70%	Less 30%
	Savings energy cost	Over 70%	40–70%	Less 40%
	Additional effects(Number of effects)	More than two	Two effects	Less than one

Table 1-2: Score of market potential

Industry1	Heat Demand	Score
Food	Medium	2
Machinery	Medium	2
Agriculture/fishery	Small	1
Electronics	Small	1
Paper/pulp	Large	3
Chemicals	Large	3

2.4 Scoring criteria items for good samples in industry

Based on the scores decided for criteria items shown in Tables 1-1 and 1-2, the score of a good practice is evaluated for criteria items of each industry. A perfect score is estimated by 27. Tables 1-3, 1-4, 1-5, and 1-6 indicate scoring results of different industries for the good practices which attain over 15 points of a total score obtained by summing up score values of criteria items.

Table 1-3 shows the score distribution for food / agriculture / fishery industries. Among the results of 15 samples having over 15 points as a total score, a sample of No. 2, simultaneous heating & cooling system in food production line, receives the highest score of 20; followed by No. 40, simultaneous heating & cooling system by heat pump using both air and water sources; and No. 83, introduction of mechanical vapor recompression (MVR) in concentrating process of salt factory, with a score of 18, respectively.

In the case of machinery / electronics industries (Table 1-4), six samples of the machinery industry have a high score over 15 points. No. 21, simultaneous heating and cooling system in cutting and cleaning processes, achieves the highest score of 22 among 98 samples.

Table 1-3: Score for food / agriculture / fishery industry

No	Industry	Location (Japan)	User (company)	HP manufacturer /constructor	Heat demand	Working fluid	Heating /cooling capacity	Supply temperature	Heat source / heat sink	Saving energy	Saving CO2 emissions	Saving energy cost	Additional effects	Total scores
2	Food	Hyogo	Kosmos Food co.Ltd.	MAYEKAWA MFG. CO., LTD	2	3	2	3	3	0	3	3	1	**20**
3	Food	Okayama	Tamura Seimen Ltd.	MAYEKAWA MFG. CO., LTD	2	3	1	3	3	0	2	1	1	**16**
4	Food	Kagoshima	Kagoshima Kumiai Chicken Food co.Ltd.	MAYEKAWA MFG. CO., LTD	2	3	1	2	1	0	2	3	1	**15**
27	Food	Gumma	Takasaki Morinaga co. Ltd.	KOBE STEEL, LTD Toshiba Carrier Corporation	1	2	3	3	2	2	2	1	1	**17**
28	Food	Hyogo	Suntory Products co.Ltd.	Mitsubishi Heavy Industries, Ltd.	2	2	2	2	2	2	2	1	0	**15**
29	Food	Tochigi	Calbee co. Ltd.	KOBE STEEL, LTD	2	2	2	2	2	2	2	0	1	**15**
30	Food	Ishikawa	Hokuriku Milk Industry co. Ltd.	MAYEKAWA MFG. CO., LTD	2	3	1	3	2	3	3	0	0	**17**
40	Food	Yamagata	Fresh Diner co. Ltd.	MAYEKAWA MFG. CO., LTD	2	3	1	3	3	2	2	2	0	**18**
41	Food	Kanagawa	Mercian Corporation	MAYEKAWA MFG. CO., LTD	2	3	2	2	3	2	2	1	0	**17**
66	Food	Aichi	Kasugai Confectionary co.Ltd.	Toshiba Carrier Corporation	2	2	1	2	1	3	3	3	0	**17**
79	Food	Aichi	Kasugai Confectionary co.Ltd.	MAYEKAWA MFG. CO., LTD	2	3	0	2	2	3	0	3	0	**15**
81	Food	Nagano	Shinshu Milkland co.Ltd.	Toshiba Carrier Corporation	2	2	1	2	1	2	2	2	1	**15**
82	Food	Chiba	Yamasa ORM co.Ltd.	MAYEKAWA MFG. CO., LTD	2	3	0	2	3	2	2	2	0	**16**
83	Food	Kochi	Muroto Deep Sea Water co.Ltd.	Sasakura Engineering Co.LTD	2	3	0	2	2	3	3	3	0	**18**
87	Food	Shizuoka	Maruhachi Muramatsu co.Ltd.	KOBE STEEL, LTD	2	2	2	1	2	3	2	2	1	**17**

Table 1-4: Score for machinery / electronics

No	Industry	Loca-tion (Japan)	User (company)	HP manufac-turer /constructor	Heat demand	Working fluid	Heating /cooling capacity	Supply tempera-ture	Heat source / heat sink	Saving energy	Saving CO2 emissions	Saving energy cost	Addi-tional effects	Total scores
21	Machinery	Aichi	Aishin A W co. Ltd.	Zeneral HP Industries, Ltd.	2	2	2	2	3	3	3	3	2	**22**
36	Machinery	Tochigi	Takaoka Electric Mfg. Co., Ltd	Mitsubishi Heavy Indus-tries, Ltd.	2	2	2	3	2	0	2	2	1	**16**
37	Machinery	Shizu-oka	Toshiba Carrier co.Ltd.	Toshiba Carrier co.Ltd.	2	2	1	3	1	2	2	2	2	**17**
85	Machinery	Naga-no	Asama Giken co.Ltd.	KOBE STEEL, LTD	2	2	0	3	2	2	2	2	0	**15**
86	Machinery	Gifu	APC Earo Speciality co.Ltd.	Toshiba Carrier Corpo-ration	2	2	2	1	1	2	2	3	0	**15**
95	Machinery	Mie	Fuji Electric co.Ltd.	Fuji Electric co.Ltd.	2	2	1	3	2	2	2	2	0	**16**

The paper products industry limits the number of samples to three good practices. Table 1-5 shows the results for the paper products industry. Only one sample of No. 5, steamless heating in broke pulper process, has a score over 15 points.

The results of the chemical industry are shown in Table 1-6. Seven samples of the chemical industry have a high score over 15 points. A sample of No. 32, introduction of hot heat pump with hot gas source in dry laminating process of package film, has the highest score of 21; following No. 43, introduction of steam heat pump in distillation process of bio-ethanol; and No. 7, introduction of heat pump with hot gas source in dry process of formed styrol, with a score of 19 and 18, respectively.

Table 1-5: Score for paper products

No	Industry	Loca-tion (Japan)	User (company)	HP manufac-turer /constructor	Heat demand	Working fluid	Heating /cooling capacity	Supply tempera-ture	Heat source / heat sink	Saving energy	Saving CO2 emissions	Saving energy cost	Addi-tional effects	Total scores
5	Paper products	Shizuo-ka	Oji To-kushushi c.Ltd.	Mitsubishi Electric Corporation	3	3	2	2	1	2	2	0	0	**15**

Table 1-6: Score for chemicals

No	Industry	Location (Japan)	User (company)	HP manufacturer /constructor	Heat demand	Working fluid	Heating /cooling capacity	Supply temperature	Heat source / heat sink	Saving energy	Saving CO2 emissions	Saving energy cost	Additional effects	Total scores
6	Chemicals	Saitama	Saiden Chemical co. Ltd.	Toshiba Carrier Corporation	3	2	2	0	3	2	2	0	1	**15**
7	Chemicals	Tochigi	Dia Chemicals co. Ltd.	MAYEKAWA MFG. CO., LTD	3	3	2	3	2	2	2	0	1	**18**
31	Chemicals	Fukui	Tanaka Chemical co.Ltd.	Mitsubishi Heavy Industries, Ltd.	3	2	2	2	2	0	2	2	1	**16**
32	Chemicals	Shizuoka	Suda Industry co.Ltd.	MAYEKAWA MFG. CO., LTD	3	3	2	2	2	3	3	3	0	**21**
38	Chemicals	Hiroshima	JMS co.Ltd.	Toshiba Carrier co.Ltd.	3	2	3	1	1	2	2	0	1	**15**
43	Chemicals	Hokkaido	Hokkaido Bioethanol co.Ltd.	KOBE STEEL, LTD	3	2	3	3	2	2	2	2	0	**19**
47	Chemicals	Saitama	Kitakami Industry co. Ltd.	MAYEKAWA MFG. CO., LTD	3	3	2	0	2	2	2	2	1	**17**

2.5 Methodology to evaluate the best practice

The best practice gives a decision maker useful information on the application of HP technology. To identify decision makers' perspectives towards the choice of best practice, it is necessary to develop a method which can prioritize the weight of criteria influencing market potential, technology and system, and installation effects.

The analytic hierarchy process (AHP) is an effective tool for dealing with complex decision making and may aid the decision maker to set priorities and make the best decision. The AHP was introduced by TL Saaty [Saaty, 1968]. The AHP method allows decision makers to investigate efficiently the different prioritization criteria in hierarchy. In the study, the method is utilized to calculate a weight of criteria item for each selected industry by structuring into the hierarchy three levels which consist of an overall goal, criteria, and sub-criteria as shown in Figure 1-1. Sub-criteria play as lower level criteria to the main criteria.

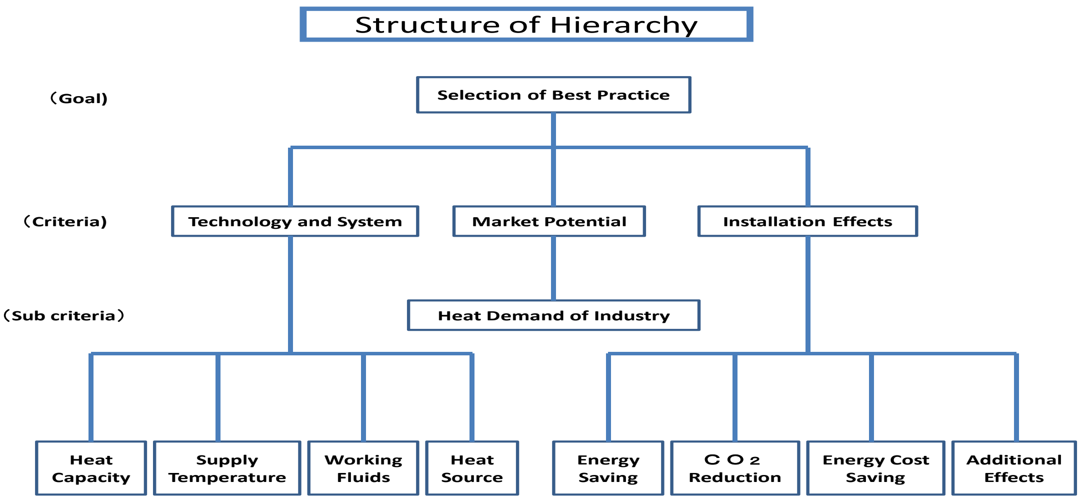


Figure 1-1: Structure of hierarchy for selection of best practice

The best practices are analyzed by the following steps.

Step 1: Computing the weight of different criteria for three different cases
Step 2: Calculating a total weighted value by summing products of weight and score
Step 3: Choosing the best practice from the ranking results of the total weighted value

2.5.1 Compute the weight of different criteria

(**Step 1**: Computing the weight of different criteria by scenario)

To compute the weights for the different criteria, the AHP begins by creating a *pairwise comparison matrix* **A**. The matrix **A** is a $m \times m$ real matrix, where m is the number of evaluation criteria considered. The relative importance between two criteria is measured according to a numerical scale from 1 to 5, as shown in Table 1-7, where it is assumed that the jth criterion is equally or more important than the kth criterion.

Table 1-7 Pairwise comparison

Value of a_{jk}	Interpretation
1	j and k are equally important
3	j is more important than k
5	j is strongly more important than k

Once the matrix $\boldsymbol{A}$ is built, it is possible to derive from $\boldsymbol{A}$ the normalized pairwise comparison matrix $\boldsymbol{A}_{norm}$ by making the sum of the entries on each column equal to 1. Finally, the criteria weight vector $\boldsymbol{w}$ (that is an m-dimensional column vector) is built by averaging the entries on each row of $\boldsymbol{A}_{norm}$

Pairwise comparison for main criteria of market potential, technology & system, and installation effects

The pairwise comparison method is used to compute the weights for the different criteria. The decision maker or stakeholder first builds a pairwise comparison matrix by answering a questionnaire. A questionnaire is built using the structured criteria and sub-criteria as follows. The larger the value of the criteria item, the better the performance of the item with respect to the corresponding criterion.

(Question) ”Please plot a point at a suitable position for two different criteria.”

IMPORTANCE	(strongly more)	(more)	(equally)	(more)	(strongly more)	
Market potential						Technology & system
Market potential						Installation effects
Technology & system						Installation effects
	5	3	1	3	5	

Pairwise comparison for sub-criteria of technology and system

(Question) “Please plot a point at a suitable position for two different sub criteria.”

IMPORTANCE	(strongly more)	(more)	(equally)	(more)	(strongly more)	
Heating capacity						Supply temperature
Heating capacity						Working fluid
Heating capacity						Heat source
Supply temperature						Working fluid
Supply temperature						Heat source
Working fluid						Heat source
	5	3	1	3	5	

Pairwise comparison for sub-criteria of installation effects

(Question) “Please plot a point at a suitable position for two different sub criteria.”

IMPORTANCE	(strongly more)	(more)	(equally)	(more)	(strongly more)	
Energy saving						CO_2 reduction
Energy saving						Energy cost saving
Energy saving						Additional effects
CO_2 reduction						Energy cost saving
CO_2 reduction						Additional effects
Energy cost saving						Additional effects
	5	3	1	3	5	

The large differences in importance are predicted for the decision of the weight of criteria items by a questionnaire survey of various types of stakeholders. We established a case study to calculate the weight of criteria items instead of a questionnaire survey. The case study is divided into the following three different cases;

Case 1: Market oriented case

Attributes to enhance market potential are regarded as important policy.

Case 2: Technology and environment-oriented case

Attributes to enhance technology and environment are regarded as important policy.

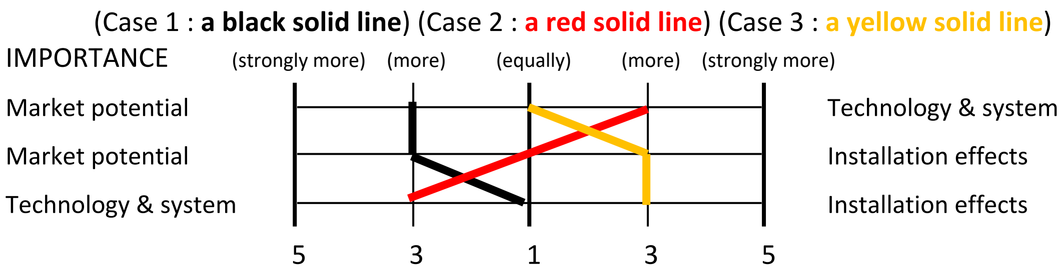
Case 3: Installation effect-oriented case

Attributes to enhance installation effects are regarded as important policy.

Pairwise comparison for main criteria

The importance of a criterion depends on the different oriented cases. For example, market potential criteria in Case 1 is higher importance than technology & system and installation effects. The level of importance for market potential is evaluated as "more" in comparison with other criteria of technology & system and installation effects in Case 1. Technology & system is the same level of importance as installation effects in Case 1. The same decision of priority is also performed for other oriented cases of technology & environment as well as installation effects as shown in Table 1-8.

Table 1-8 Pairwise comparison of main criteria for three different cases



As for sub-criteria, the importance of a criterion is decided by each oriented case.

Pairwise comparison for sub-criteria of „technology & system"

(**Case 1**: Market oriented case)

Case 1 gives a priority to the sub-criteria items related to market potential. Heating capacity as well as supply temperature are strongly more important than working fluid. Heating capacity has the same level of importance as supply temperature. Heating capacity is more important than heat source. Heat source is more important than working fluid.

(**Case 2**: Technology and environment-oriented case)

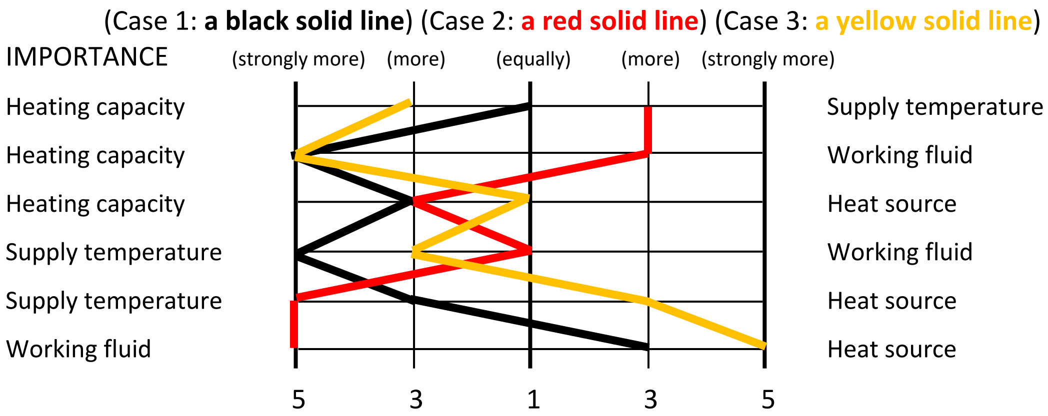
Case 2 gives a priority to sub-criteria items related to technology and environment. Supply temperature as well as working fluid are strongly more important than heat source. Supply temperature has the same level of importance as working fluid. Working fluid is more important than heating capacity. Heating capacity is more important than heat source.

(**Case 3**: Installation effect-oriented case)

Case 3 gives a priority to sub-criteria items related to installation effects. Heating capacity as well as heat source are strongly more important than working fluid. Heating capacity has the same level of importance as heat source. Heating capacity is more important than supply temperature. Supply temperature is more important than working fluid.

Table 1-9 indicates results of pairwise comparison for sub-criteria items of technology & system evaluated by three different cases.

Table 1-9 Pairwise comparison for sub criteria of technology and system



Pairwise comparison for sub criteria of installation effects

(**Case 1**: Market-oriented case)

Case 1 gives a priority to sub-criteria items related to market potential. From the economical points of view, energy cost saving is strongly more important than energy saving as well as CO_2 reduction, and it is more important than additional effects. Additional effect is more important than energy saving as well as CO_2 reduction. Energy saving has the same level importance as CO_2 reduction.

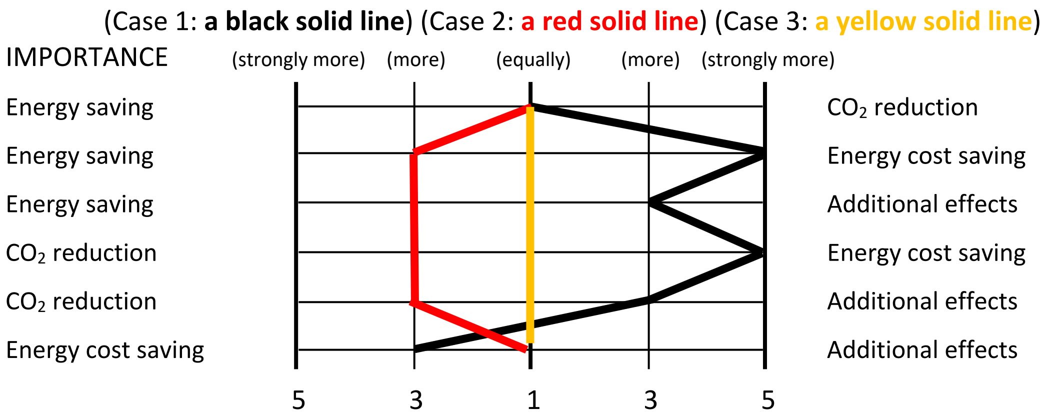
(**Case 2**: Technology and environment-oriented case)

Case 2 gives a priority to sub-criteria items related to technology and environment. Energy saving has the same level of importance as CO_2 reduction. Energy saving as well as CO_2 reduction is more important than energy cost saving and additional effect. Energy cost saving has the same level importance as additional effect.

(**Case 3**: Installation effect-oriented case)

Case 3 gives a priority to sub-criteria items related to installation effect. All sub-criteria items of installation effects equally have the same level importance in Case 3. Table 1-10 indicates results of pairwise comparison for sub-criteria items of installation effect evaluated by three different cases.

Table 1-10: Pairwise comparison for sub criteria of installation effect



Based on the survey of pairwise comparison with three different cases, values of the weight are calculated for main criteria as well as sub-criteria of three different cases as shown in Table 1-11.

Table 1-11: Value of weight for main criteria and sub criteria of three different cases

Main criteria	Value of weight		
	Case 1	Case 2	Case 3
Market	0.6	0.2	0.2
Technology & system	0.2	0.6	0.2
Effects	0.2	0.2	0.6

Sub criteria of technology and system	Value of weight		
	Case 1	Case 2	Case 3
Heating capacity	0.078	0.091	0.100
Supply temperature	0.078	0.235	0.058
Working fluid	0.013	0.235	0.013
Heat source	0.030	0.040	0.029

Sub criteria of installation effects	Value of weight		
	Case 1	Case 2	Case 3
Savings energy	0.019	0.075	0.05
Savings CO_2 emission	0.019	0.075	0.05
Savings cost	0.112	0.025	0.05
Additional effects	0.050	0.025	0.05

The weights in Table 1-11 are utilized to calculate a total weighted value for each good practice.

2.5.2 Calculate a total weighted value

(**Step 2**: Calculating a total weighted value by summing products of weight and score)

A total weighted value of a sample can be calculated by summing a product of weight indicated in Table 1-10 and score obtained by Tables 1-3, 1-4, 1-5, and 1-6. The value is calculated for selected good practices of food / agriculture / fishery, machinery / electronics, paper products, and chemicals industries. The results are indicated in Table 1-12.

Table 1-12: A total weighted value of three different oriented cases for good practices of industries
(yellow : the best, blue : the second best)

1) Food/agriculture/fishery industry No. 2

No	Title of project	Industry	Location (Japan)	User (company)	HP manufacturer /constructor/consultant	Total scores	Total weighted value		
							Case 1	Case 2	Case 3
2	Simultaneous heating & cooling system in food production line	Food	Hyogo	Kosmos Food co.Ltd.	MAYEKAWA MFG. CO., LTD	20	2.16	2.44	1.25
3	Simultaneous heating & cooling system in noodle production process	Food	Okayama	Tamura Seimen Ltd.	MAYEKAWA MFG. CO., LTD	16	1.84	2.22	1
4	Reduction of boiler load by heating supply water in scalder process	Food	Kagoshima	Kagoshima Kumiai Chicken Food co.Ltd.	MAYEKAWA MFG. CO., LTD	15	1.93	1.96	0.98
27	Introduction of sets of heat pump in cleaning, product preservation and air conditioning processes of biscuit factory	Food	Gumma	Takasaki Morina-ga co. Ltd.	KOBE STEEL, LTD Toshiba Carrier Corporation	17	1.39	2.08	1.06
28	Introduction of turbo type heat pump in beverage factory	Food	Hyogo	Suntory Products co.Ltd.	Mitsubishi Heavy Industries, Ltd.	15	1.79	1.93	1.05
29	Self exhaust heat recovery in waste water reprocessing facility of snack confectionery factory	Food	Tochigi	Calbee co. Ltd.	KOBE STEEL, LTD	15	1.72	1.93	1.05
30	Simultaneous heating & cooling system in cooling and cleaning processes of ice cream factory	Food	Ishikawa	Hokuriku Milk Industry co. Ltd.	MAYEKAWA MFG. CO., LTD	17	1.73	2.43	1.07
40	Simultaneous heating & cooling system by heat pump using both air and water sources	Food	Yamagata	Fresh Diner co. Ltd.	MAYEKAWA MFG. CO., LTD	18	1.94	2.37	1.1
41	Simultaneous heating & cooling system by heat pump in winery	Food	Kanagawa	Mercian Corpora-tion	MAYEKAWA MFG. CO., LTD	17	1.83	2.2	1.09
66	Introduction of circulating heating type heat pump in chocolate hot water concoction process	Food	Aichi	Kasugai Confec-tionary co.Ltd.	Toshiba Carrier Corporation	17	1.94	2.00	1.12
79	Introduction of circulating heating type heat pump in thermal process of confectionery factory	Food	Aichi	Kasugai Confec-tionary co.Ltd.	MAYEKAWA MFG. CO., LTD	15	1.85	1.96	0.91
81	Introduction of circulating heating type heat pump in dairy produc-tion factory	Food	Nagano	Shinshu Milkland co.Ltd.	Toshiba Carrier Corporation	15	1.84	1.85	1.02
82	Simultaneous heating & cooling system in brewing process of soy sauce	Food	Chiba	Yamasa ORM co.Ltd.	MAYEKAWA MFG. CO., LTD	16	1.76	2.05	0.94
83	Introduction of MVR in concen-trating process of salt factory	Food	Kochi	Muroto Deep Sea Water co.Ltd.	Sasakura Engineer-ing Co.LTD	18	1.91	2.18	1.06
87	Introduction of exhausted heat recovery type heat pump in soup stock production factory	Food	Shizuoka	Maruhachi Muramatsu co.Ltd.	KOBE STEEL, LTD	17	1.89	1.82	1.14

2) Machinery/electronics No. 21

No	Title of project	Industry	Location (Japan)	User (company)	HP manufacturer /constructor/consultant	Total scores	Total weighted value		
							Case 1	Case 2	Case 3
21	Simultane-ous heating & cooling system in cutting and cleaning processes	Machin-ery	Aichi	Aishin A W co. Ltd.	Zeneral HP Industries, Ltd.	22	2.18	2.22	1.38
36	Introduction of heat pump with hot water source in dry process of transformer production factory	Machin-ery	Tochigi	Takaoka Electric Mfg. Co., Ltd	Mitsubishi Heavy Industries, Ltd.	16	1.99	2.06	1.11
37	Introduction of heat pump to keep chemi-cal solvent warm in surface treating pro-cess	Machin-ery	Shizuo-ka	Toshiba Carrier co.Ltd.	Toshiba Carrier co.Ltd.	17	1.93	1.96	1.03
85	Introduction of exhausted heat recov-ery type heat pump in cleaning process of automobile parts	Machin-ery	Nagano	Asama Giken co.Ltd.	KOBE STEEL, LTD	15	1.82	2.01	0.96
86	Introduction of heat pump chiller in painting process of aviation and space trans-portation equipment	Machin-ery	Gifu	APC Earo Speciality co.Ltd.	Toshiba Carrier Cor-poration	15	1.9	1.7	1.06
95	Introduction of steam heat pump in cleaning process be-fore painting of vending machine production factory	Machin-ery	Mie	Fuji Elec-tric co.Ltd.	Fuji Electric co.Ltd.	16	1.90	2.10	1.06

3) Paper products

No	Title of project	Industry	Location (Japan)	User (company)	HP manufacturer /constructor/consultant	Total scores	Total weighted value		
							Case 1	Case 2	Case 3
5	Steamless heating in broke pulper process	Paper products	Shizuoka	Oji Tokushushi c.Ltd.	Mitsubishi Electric Corporation	15	2.26	2.3	1.18

4) Chemicals No. 32

No	Title of project	Industry	Location (Japan)	User (company)	HP manufacturer /constructor/consultant	Total scores	Total weighted value		
							Case 1	Case 2	Case 3
6	Electric load leveling by water heat storage system in coolong process of reaction tank	Chemicals	Saitama	Saiden Chemical co. Ltd.	Toshiba Carrier Corporation	15	2.20	1.70	1.16
7	Introduction of heat pump with hot gas source in dry process of formed styrol	Chemicals	Tochigi	Dia Chemicals co. Ltd.	MAYEKAWA MFG. CO., LTD	18	2.42	2.60	1.32
31	Introduction of heat pump with hot water source recovering waste heat in battery materials produc-tion factory	Chemicals	Fukui	Tanaka Chemical co.Ltd.	Mitsubishi Heavy Industries, Ltd.	16	1.91	1.83	1.05
32	Introduction of hot heat pump with hot gas source in dry laminat-ing process of package film	Chemicals	Shizuoka	Suda Industry co.Ltd.	MAYEKAWA MFG. CO., LTD	21	2.66	2.56	1.46
38	Improving control performance of air conditioning temperature by module chiller in medical apliance production factory	Chemicals	Hiroshima	JMS co.Ltd.	Toshiba Carrier co.Ltd.	15	2.29	1.94	1.26
43	Introduction of steam heat pump in distillationprocess of bioethanol	Chemicals	Hokkaido	Hokkaido Bioeth-anol co.Ltd.	KOBE STEEL, LTD	19	2.65	2.48	1.46

47	Introduction of heat pump with hot gas source in dry laminating process of package film	Chemicals	Saitama	Kitakami Industry co. Ltd.	MAYEKAWA MFG. CO., LTD	**17**	**2.41**	**1.94**	**1.25**

2.5.3 Choose the best practice

(**Step 3**: Choosing the best practice from the ranking results of the total weighted value)

Ranking results of good practices are listed in Table 1-12. The yellow color means the best option gaining the highest value and the blue color is the next best option for each industry in the table. We choose the best practice which can achieve over three highest values among total scores and total weighted values from tables. Table 1-13 shows the best practice selected for each industry

Table 1-13 The best practice to be selected for each industry

No	Title of project	Industry	Location (Japan)	User (company)	HP manufacturer /constructor/consultant	Total scores	Total weighted value		
							Case 1	Case 2	Case 3
2	Simultaneous heating & cooling system in food production line	Food	Hyogo	Kosmos Food co.Ltd.	MAYEKAWA MFG. CO., LTD	**20**	**2.16**	**2.44**	**1.25**
21	Simultaneous heating & cooling system in cutting and cleaning processes	Machinery	Aichi	Aishin A W co. Ltd.	Zeneral HP Industries, Ltd.	**22**	**2.18**	**2.22**	**1.38**
32	Introduction of hot heat pump with hot gas source in dry laminating process of package film	Chemicals	Shizuoka	Suda Industry co.Ltd.	MAYEKAWA MFG. CO., LTD	**21**	**2.66**	**2.56**	**1.46**

With regard to the paper products industry, it is difficult to choose the best practice because of the limited number of samples as well as the low score. The best practice of each industry is described in detail in Chapter 3.

3 Best Practices of IHP Application

In this chapter, the best practices of each industry are described in detail.

3.1 Best practice of food/agriculture/fishery industry; No. 2

The first best practice selected is the food / agriculture / fishery industry. This practice is an application of simultaneous heat pumps to freeze-dried foods production. Table 1-14 shows the outline of the installation.

In the freeze-dried foods manufacturing plant, there are steam and hot water demands for food processing machines, and hot water demand for sterilization and washing processes. In addition, there is cooling demand for building air conditioning.

As shown in Figure 1-2, steam had been supplied by a heavy oil boiler, and hot water had been supplied by mixing the steam with feed water. This method of supplying hot water caused energy loss. Moreover, chilled water had been supplied by an absorption chiller. Overlap in the supply of heating and cooling had existed. It is a waste to consume energy for heating and cooling separately.

The renewal date for the absorption chiller was approaching. On that occasion, the heat pump was installed for simultaneous heating and cooling. A hot water tank was also installed for use during off-peak electric billing periods. The thermal storage of hot water and chilled water can cope with unbalance between heating and cooling demands.

Figure 1-3 shows the change of heat source equipment. Three units of 80 kW/unit water-to-water heat pumps were installed. The heat pump is a trans-critical cycle heat pump using carbon dioxide as working fluid and supplies hot water at 90 °C by heating feed water at 15 °C. This heat pump installation can replace two steam boilers and one absorption chiller.

Figure 1-4 shows the external appearance of installed heat pumps and hot water tank.

Table 1-14: Outline of installation

Industry	Food (Freeze-dried foods production)
Processes	Food processing, Sterilization, Washing, Building air-conditioning
Application	Simultaneous hot water and cold water supply
Purpose	Renewal of facilities, Energy saving, Energy cost reduction
Installed year	2008
System	Water-to-water heat pumps (80 kWh/unit, 3 units)
Effects	87% CO_2 emissions reduction, 80% energy cost reduction

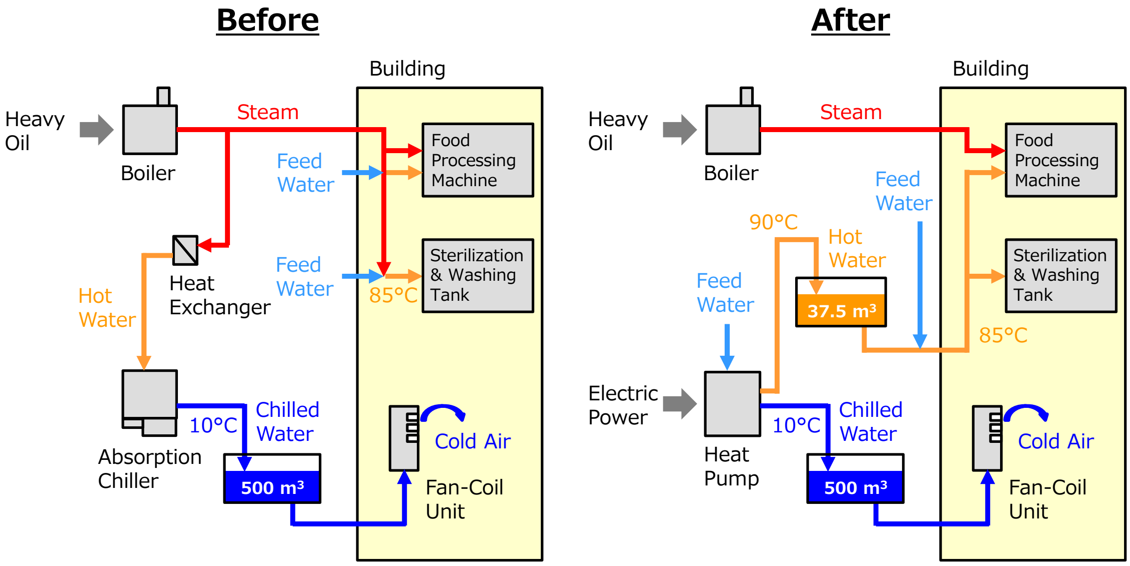


Figure 1-2: System flowchart [HPTCJ, 2011]

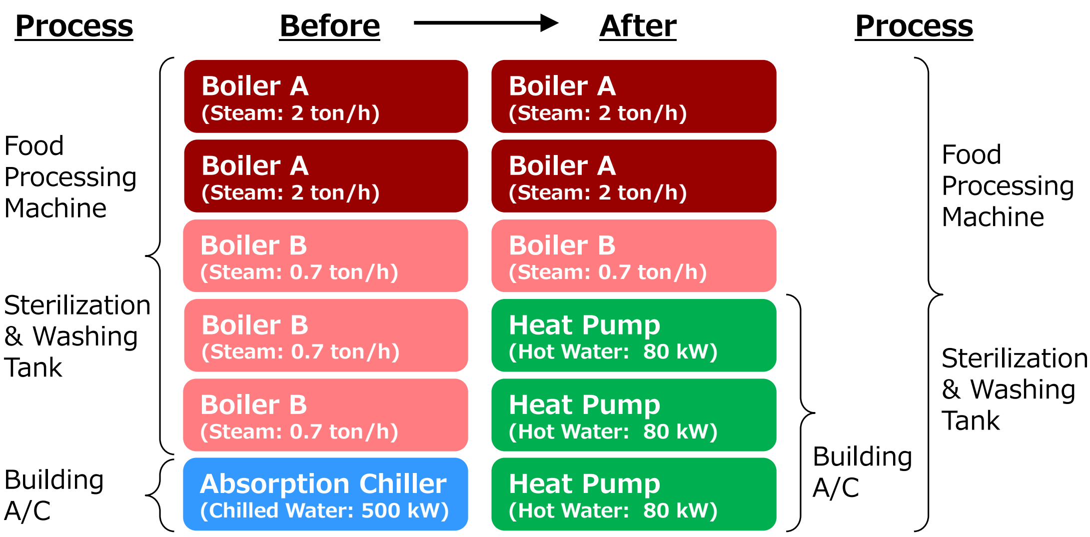


Figure 1-3: Heat source equipment

(a) Heat pumps (80 kW/unit, 3 units)

(b) Hot water tank (37.5 m^3)

Figure 1-4: External appearance of installed heat pumps and hot water tank [HPTCJ, 2011]

Figure 1-5 shows the heat pump operation. All three heat pumps are usually operated during the night, an application to lower the electric bill, using thermal storage. If the tank runs short of hot water, the heat pumps are automatically operated (see 16:00 ~ 18:00).

As shown in Table 1-15, very large effects were obtained by applying the heat pumps. The heat pumps achieved CO_2 emissions reduction by 87% and energy cost reduction by 80%. The simple payback period was estimated to be five years.

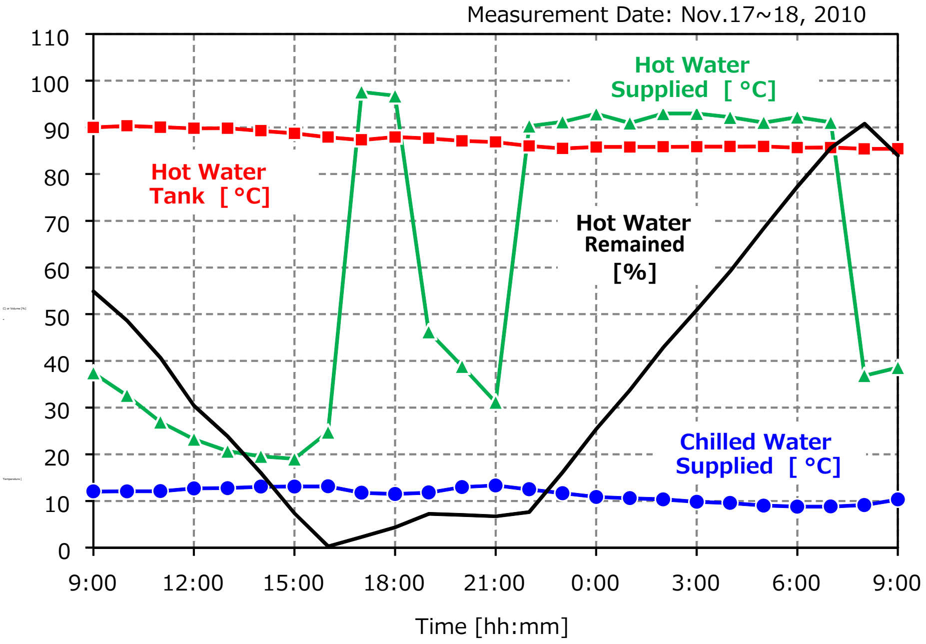


Figure 1-5: Operation of heat pump [Yokoyama, 2011]

Table 1-15 Effects of applying the heat pump [2]

CO_2 emissions	87% reduction, 450 ton-CO_2/year reduction
Energy cost	80% reduction
Payback period	5 years (estimated)

* CO_2 emission factor:
- Electricity: 0.282 kg-CO_2/kWh (KEPCO, 2008~2009)
- Heavy oil: 2.71 kg-CO_2/L

3.2 Best practice of machinery/electronics industry; No. 21

The second best practice selected is the machinery/electronics industry. The application of heat pumps to cutting and washing processes (No. 21) will be shown as the best practice of the machinery industry in Japan [IPEEC, 2016a], [IPEEC, 2016b].

Mechanical part manufacturing plants have cutting processes followed by washing processes. The conventional system for cutting and washing processes is shown in Figure 1-6. In the cutting processes, cutting liquid is cooled and the temperature is maintained at approximately 20 or 30 °C. Cold water at approximately 15 or 25 °C is necessary to cool the cutting liquid. Cutting liquid was conventionally cooled by small chillers. The coefficient of performance (COP) of the small chillers was 2. Exhaust heat from the chiller was released to the atmosphere.

In the washing processes, washing liquid is heated and the temperature is maintained at approximately 60 °C. Hot water at approximately 65 °C is necessary to heat the washing liquid. Washing liquid was heated by electric heaters or hot steam from boilers. Generally, boiler rooms are located far from factory buildings in which the washing processes are installed. In this case, steam is supplied from the boiler to the washing machines located 300 m away as shown in Figure 1-7. Not only combustion loss and drain recovery loss but also huge heat loss from the steam piping substantially lowered total energy efficiency. The total thermal efficiency of the steam supply system was 0.2.

To improve energy efficiency, high-efficiency heat pumps were desired to be installed near washing processes for energy saving as shown in Figure 1-8.

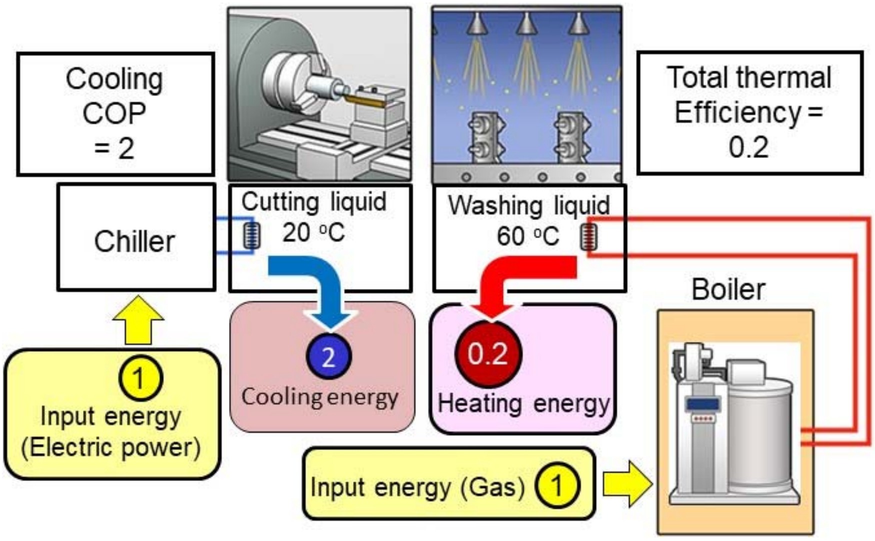


Figure 1-6: Conventional system for cutting and washing processes

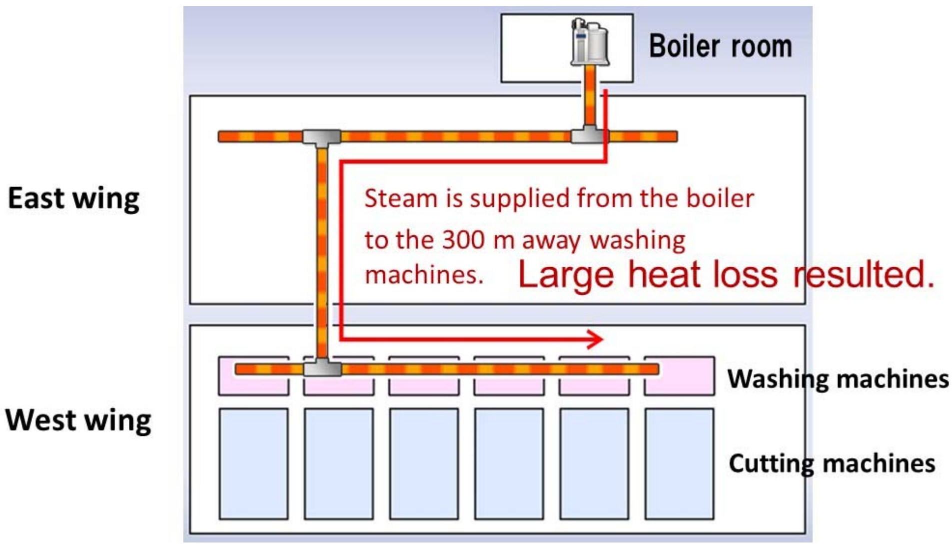


Figure 1-7: Ground plan of the factory

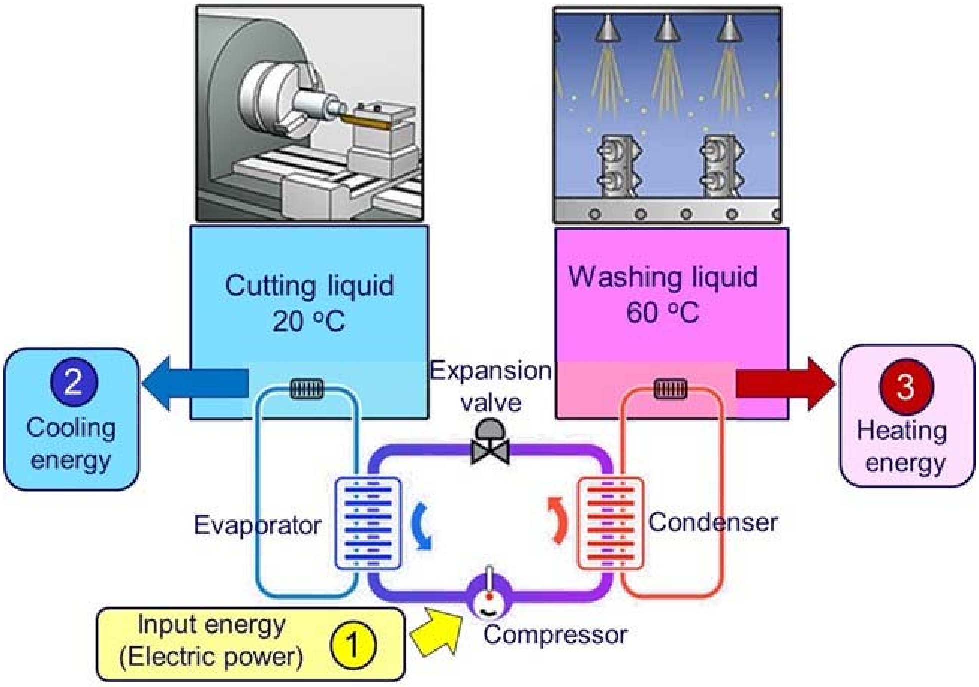


Figure 1-8: Application of heat pumps to cutting and washing processes

There are three technical issues shown in Figure 1-9. The first issue is highly efficient hot water circulation heating (60‑65 °C). The second issue is countermeasure against contamination of air-refrigerant heat exchangers with oil mist and dust. The third issue is countermeasure against unbalance between heating and cooling demands.

The refrigerant R134a was selected for the first issue. Oil mist filters were equipped standardly for the second issue. The third issue was important. Next, the development of the heat pumps was carried out.

The countermeasure against unbalance between heating and cooling demands has been completed by switching three operation modes such as simultaneous heating & cooling operation mode, heating operation mode, and cooling operation mode as shown in Figure 1-10. Figure 1-11 shows a simultaneous heating & cooling operation mode. Total COP reaches 5. Figure 1-12 shows a heating operation mode. The heating COP is 3. Figure 1-13 shows a cooling operation mode. The cooling COP reaches 5.

The developed heat pump has the following features:

(1) The heat pump has a total COP of 5 under the simultaneous cooling and heating condition.
(2) The heat pump can accommodate unbalanced cooling and heating demands.
(3) The heat pump is oil-mist proof with oil-mist filters on the air-refrigerant heat exchanger and user-friendly with an easily-manipulated touch-panel.

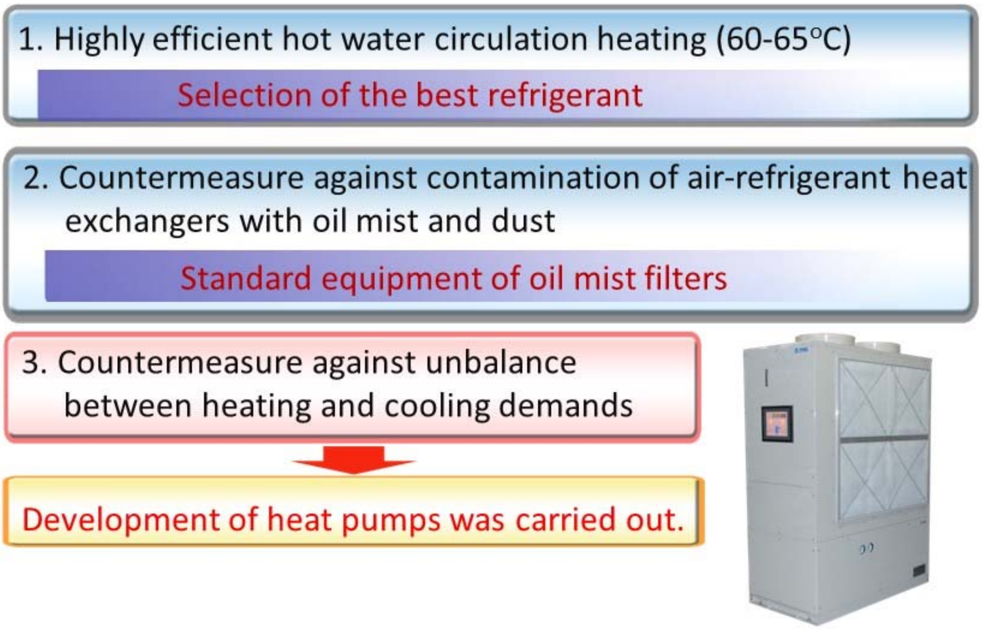


Figure 1-9: Technical issues

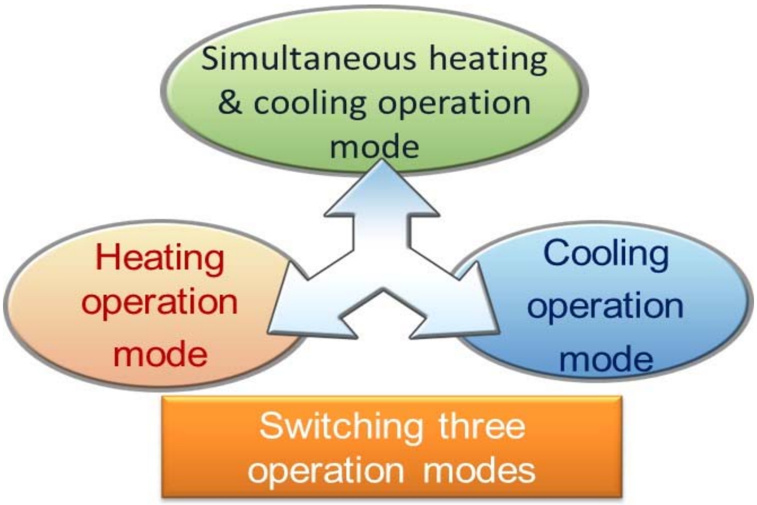


Figure 1-10: Countermeasure against unbalance between heating and cooling demands

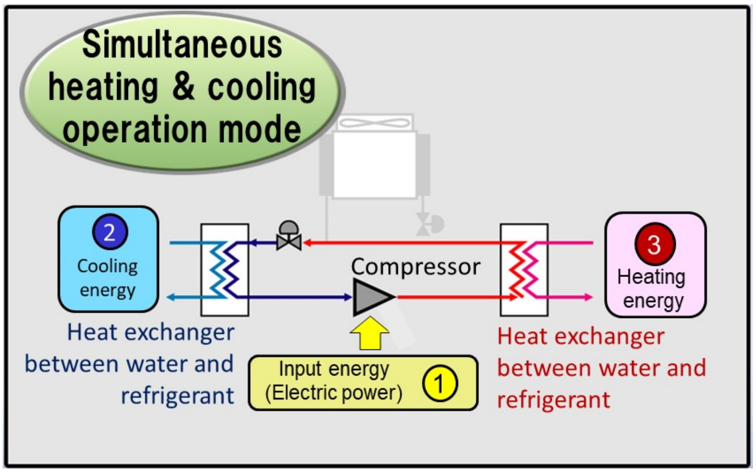


Figure 1-11: Simultaneous heating & cooling operation mode

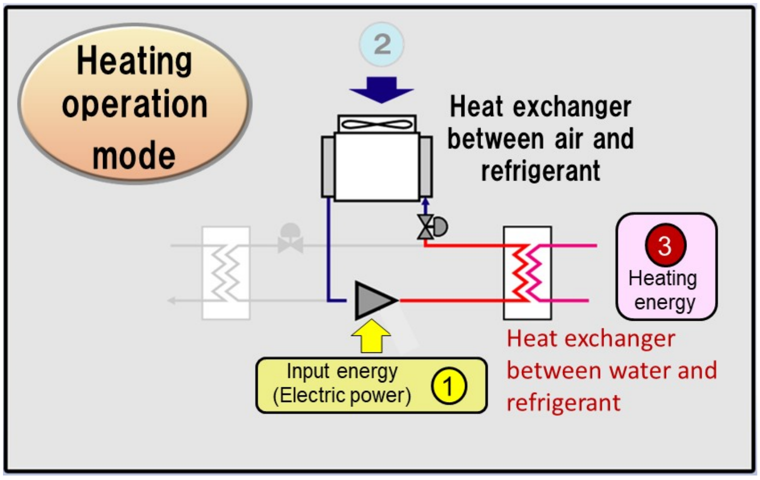


Figure: 1-12: Heating operation mode

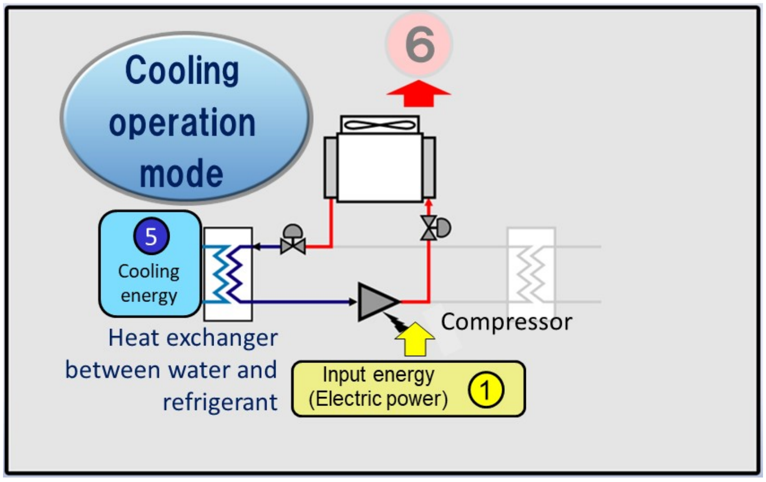


Figure 1-13: Cooling operation mode

To begin with, a heat pump for a washing process and a cutting process was installed in 2009, as shown in Figure 1-14.

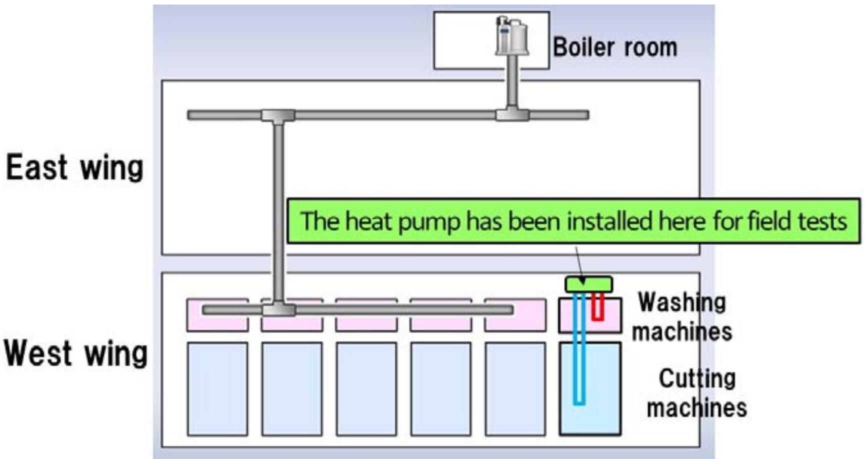


Figure 1-14: Ground plan of the factory

Figure 1-15 shows the installation of the heat pump. Tube type heat exchangers were set in the six cutting liquid baths. A plate type heat exchanger was set between the washing liquid loop and the hot water loop.

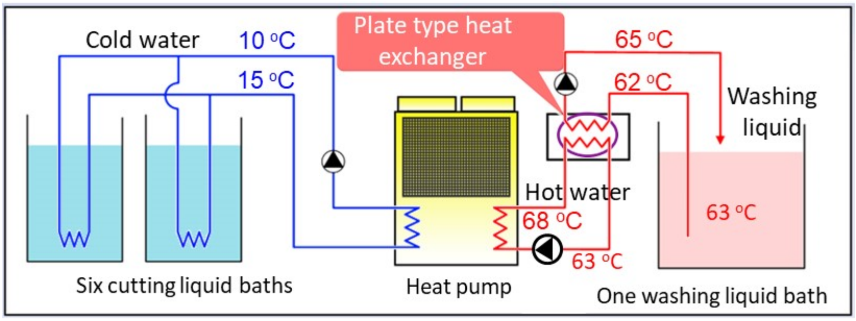


Figure 1-15: Installation of the heat pump

Figure 1-16 shows the field test results regarding temperatures. The trend curve of washing liquid temperature is shown in the figure. Washing liquid was kept at nearly 62 °C. Cutting liquid temperature was adjusted nearly the same as the temperature of the cutting machine.

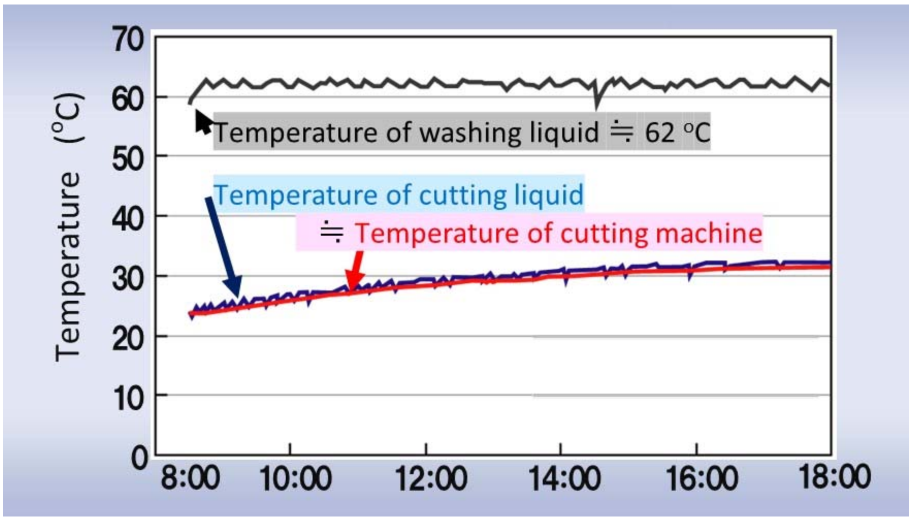


Figure 1-16: Field test results (temperatures)

Figure 1-17 shows the field test results regarding heat demands and operation modes. Red vertical bars show the trend curves of heating demands and light blue vertical bars show the trend curves of cooling demands. As for operation modes, green lateral bars show heating & cooling modes, blue lateral bands show heating modes, and an orange lateral bar shows a cooling mode.

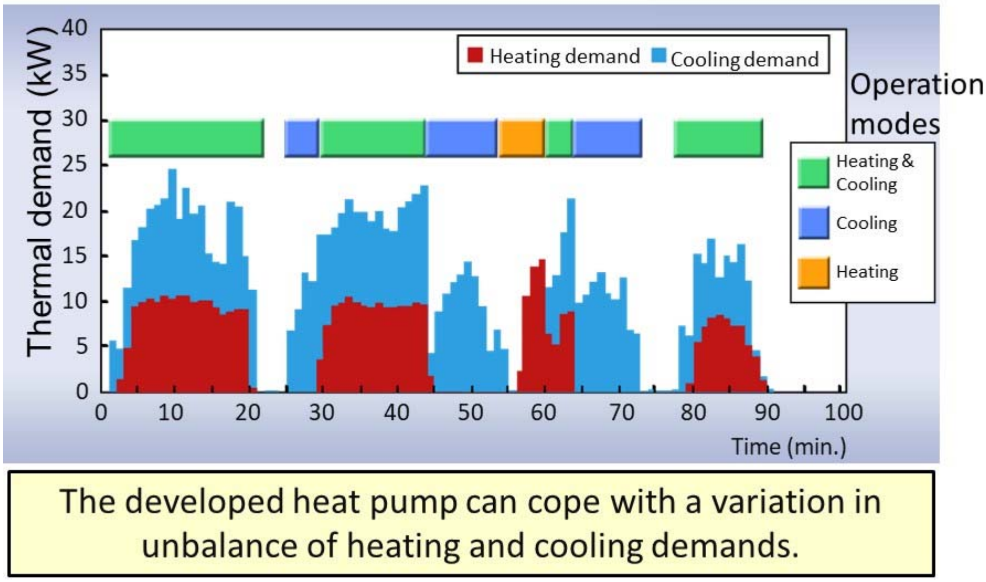


Figure 1-17: Field test results (heat demands and operation modes)

After the effect of the heat pump integration was verified through field tests, 13 more heat pumps were installed in 2010. These 14 heat pumps consist of six cooling/heating type machines with a heating capacity of 22 kW and eight heating-only type machines with a heating capacity of approximately 44 kW.

Table 1-16 shows the effects of the application of heat pumps regarding energy. Power consumption increased, but the consumption of fuel oil and water decreased to zero because the new system no longer uses heavy oil as fuel and water from the steam boiler. Moreover, primary energy consumption and CO_2 emissions were reduced by 84% and 80%, respectively.

Table 1-16 Effects of application of heat pumps (Energy)

	Before application of heat pumps	**After application of heat pumps**	**Reduction achived**
Power consumption (MWh / year)	193 (100%) <Boiler axiliary equipment, Cooler>	570 (295%) <Heat pumps>	**+377 (+195%)**
Fuel oil consumption (Kilo Litters / year)	470 (100%) <Boiler fuel oil>	0 (0%) <Heat pumps>	**-470 (-100%)**
Energy saving (Fuel oil equivalent, KL/ year)	522 (100%) <Boiler, Cooler>	85 (16%) <Heat pumps>	**-437 (-84%)**
Water consumption (KL/ year)	6,953 (100%) <Steam>	0 (0%) <Heat pumps>	**-6,953 (-100%)**
CO_2 emissions (Tons of CO_2 / year)	1,364 (100%) <Boiler, Cooler>	270 (20%) <Heat pumps>	**-1,094 (-80%)**

Table 1-17 shows the effects of the application of heat pumps regarding cost. Comparing results before and after the application of heat pumps, investment cost decreased by 33.2% and annual running cost decreased by 79.1%. When the heat pump system is added to the conventional system, the initial equipment investment cost is 91,000,000 JPY; running cost reduction is 26,030,000 JPY per year; and subsequently the pay-back time becomes 3.5 years. When a factory is newly founded, both initial investment cost and running cost of the heat pump system are lower than those of the conventional steam supply system and chillers.

Approximately 110 heat pumps had been installed in Japan as well as Japan's neighbors by 2017.

Table 1-17 Effects of application of heat pumps (Cost)

	Before application of heat pumps	After application of heat pumps	Reduction achived
Investment cost	Boilder (Including piping): 75,300,000 JPY Steam heater: 10,500,000 JPY Cooler: 50,400,000 JPY Total: 136,200,000 JPY (100%)	Heat pump system (14 units) **Total 91,000,000 JPY** (66.8%)	45,200,000 JPY or 33.2 %
Annual running cost	Electricity: 193 MWh, 2,340,000 JPY Fuel oil: 470 KL, 28,130,000 JPY Water: 6.953 KL, 2,450,000 JPY Total: 32.920,000 JPY (100%)	Electricity: 570 MWh, 6,890,000 JPY Total: 6,890,000 JPY (20.9%)	**26,030,000 JPY** or 79.1%

3.3 Best practice of chemicals; No. 32

The third best practice selected is the chemical industry. This practice is an application of the hot air supply heat pump to the drying process when laminating film. Table 1-18 shows the outline of the installation.

Figure 1-19 shows the packaging film production process. In the converting industry where printing and multifunctional materials are laminated on plastic film, etc., the process consumes a large amount of fossil fuel in order to dry inks, adhesives, and coating materials used during processing. In addition, installing a volatile organic compound (VOC) processor was advanced by the amendment of the Air Pollution Control Act, which increased fossil fuel consumptions.

Table 1-18 Outline of installation [JEHC, 2013]

Industry	Chemicals (Packaging film production)
Processes	Drying when laminating film
Application	Hot air supply
Purpose	Effective use of exhaust heat from VOC processor
Installed year	2011
System	Water-to-air heat pumps (108 kWh)
Effects	72% CO_2 emissions reduction, 75% energy cost reduction

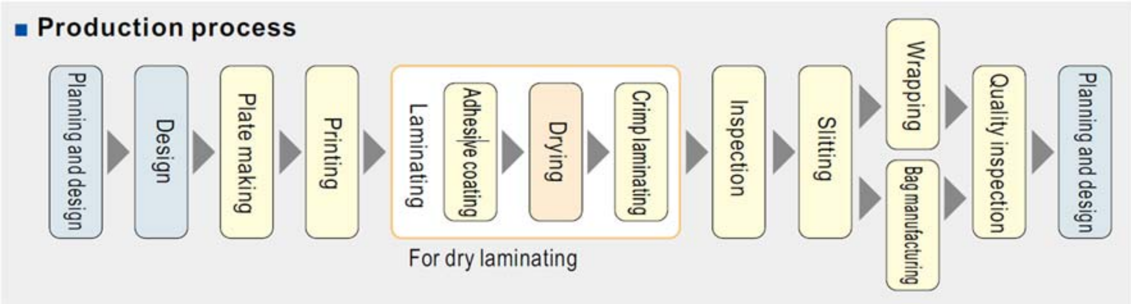


Figure 1-19: Production process [JEHC, 2013]

In 2010, in response to the VOC emissions regulations, the factory installed a VOC processor. By heating the VOC to as high as 800 °C, the processor makes it harmless against an environment. In the meantime, it generates about 55 °C of exhaust heat that is discharged to the outside.

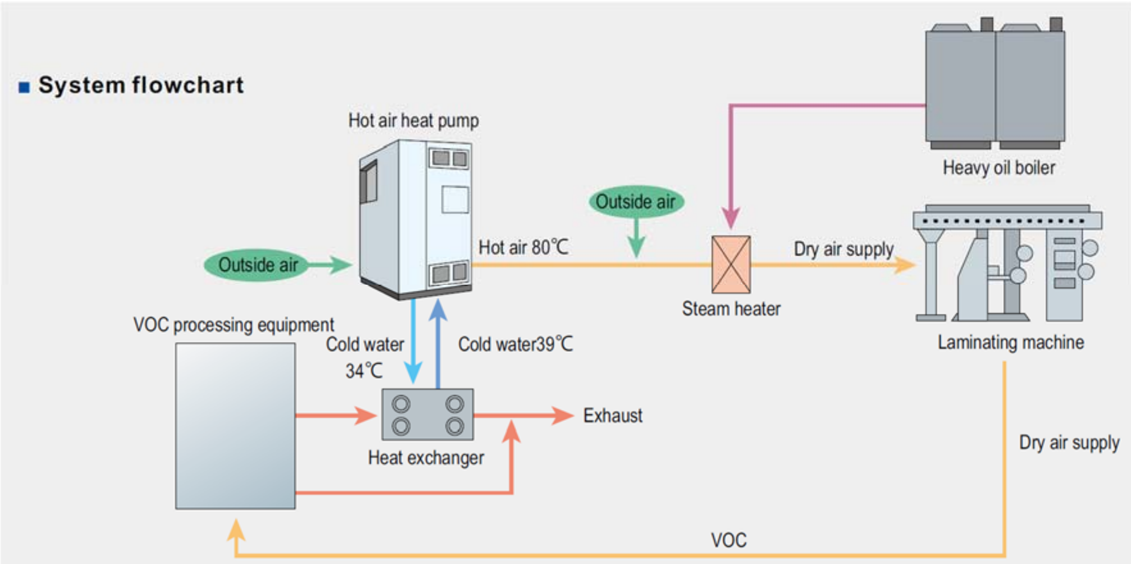


Figure 1-20: System flowchart [JEHC, 2013]

A hot air supply heat pump was installed in 2011 in order to gain effective use of the exhaust heat from VOC processor. As shown in Figure 1-20, the heat pump uses 39 °C water heat-exchanged with exhaust gas as the heat source and supplies 80 °C of hot air. The hot air is used as a pre-heater, which can reduce steam consumption by the heavy oil boiler.

Figure 1-21 shows external appearance of installed heat pumps. Heat pumps take in outside air and supply hot air.

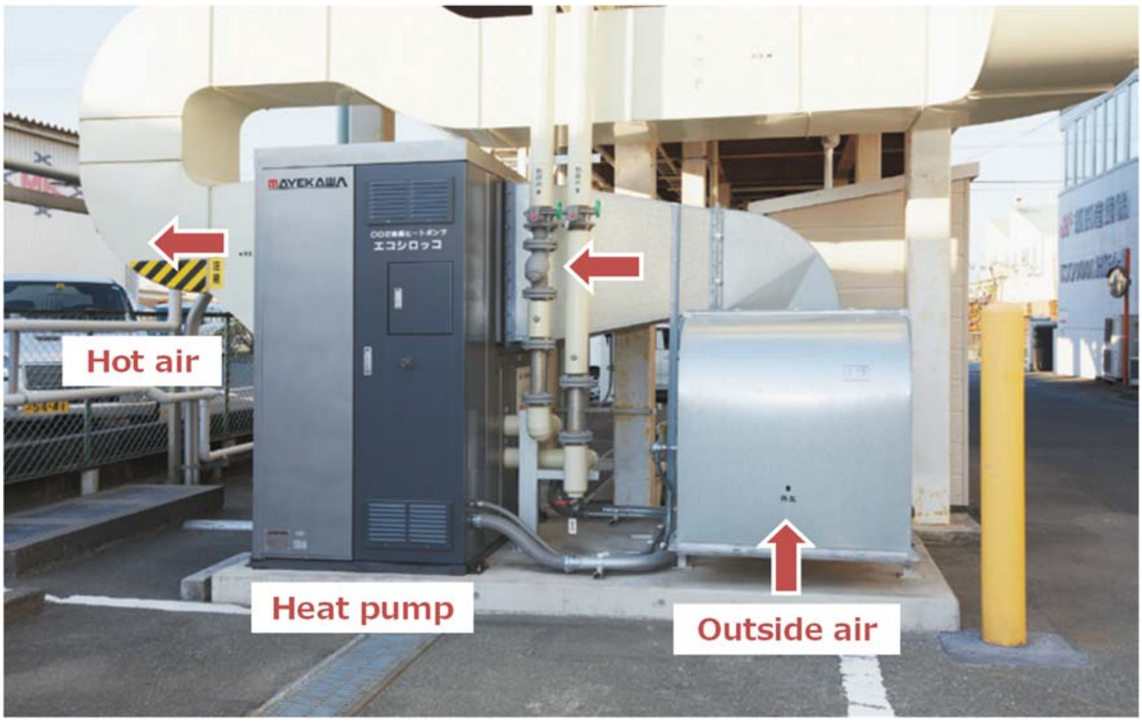


Figure 1-21: External appearance of installed heat pump [Fukasawa, 2012]

As shown in Table 1-19, very high effects were obtained by applying the heat pumps. The heat pumps achieved primary energy consumption reduction of 60%, CO_2 emissions reduction of 72%, and energy cost reduction of 75%. The simple payback period was not published.

Table 1-19 Effects of installed heat pump [JEHC, 2013]

Primary energy consumption	60% reduction
CO_2 emissions	72% reduction
Energy cost	75% reduction

*Primary energy conversion factor:

- Electricity: 9.97 MJ/kWh
- Heavy oil: 39.1 MJ/L

* CO_2 emission factor:

- Electricity: 0.473 kg-CO_2/kWh (Chubu Electric Power, 2010)
- Heavy oil: 2.71 kg-CO_2/L

4 Issues required for practical application

4.1 Problems of heat usage in factories

Various types of energy, such as electricity, natural gas, and oils, are consumed to produce final products. A centralized supply system (energy center system) is often adopted into the large-scale factory. The system comprises one centralized plant, which supplies chilled water, hot water, and steam through pipes to multiple production processes in buildings located everywhere on the premises for use in production.

As a heating medium, steam is used in almost all factories because it is easy to use. High efficiency steam generators (boilers) are already installed almost in all factories. Focusing on the usage of steam in the factory, however, it appears that a large amount of steam is actually lost before it is used.

There are four major problems in supplying heat in the factory, as described below.

(A) Large amount of low temperature waste heat

In production processes in the factory, heat is wasted in different forms. All energy inputs into the factory are finally wasted as low level thermal energy.

(B) Low effective use of steam

There is a survey result that about 50% of the steam generated from the boiler is lost before use in the process. These losses seem to be caused by heat loss in piping and drain loss. There is a need to improve net heat utilization in factories.

(C) Uniform heat supply temperature

The temperature of the heating medium required for each production process, such as heating, drying, washing, etc., is different. The steam supply system generates steam at the highest required temperature and supplies heat of uniform temperature for different processes. Large energy losses may occur.

(D) Individual equipment installed in heating and cooling processes

Heating equipment and cooling equipment are separately installed in the production system using both heating and cooling.

These problems can be solved by the application of a heat pump which has various advantages in heat supply, described as follows:

(1) Heating up from low to high temperature by means of a small energy
(2) Recoverable use of various heat sources such as exhausted hot water, underground water, ambient air, exhausted hot gas, etc.
(3) Simultaneous heating and cooling

It may be possible to reduce primary energy, reduce CO_2 emissions, and reduce running costs up to approximately 50% by achieving these advantages. IHPs are expected to create innovations in the heat supply system for energy conservation and CO_2 reduction in the industrial sector.

4.2 Barriers to installation

Industrial heat pumps (IHPs) have recently been introduced mainly in developed countries, but actual industry application is limited in spite of their possessing large market potential with a large amount of heat consumption. To successfully apply heat pumps for the industrial sector, there are barriers to overcome.

The main eight barriers are classified into four categories and listed below.

(A) Industrial Barriers

(1) Lack of knowledge and experience with heat pumps
(2) Lack of data about heating demand and exhaust heat
(3) Lack of engineering companies specialized in industrial heat pumps

(B) Technical Barriers

(4) Limitation of achievable temperature by heat pump
(5) Temporal and spatial gap between heating demand and waste heat

(C) Economic Barriers

(6) Long pay back periods
(7) Hidden costs

(D) Legal Barriers

(8) Legal Barriers

Barriers and measures obtained by a survey for heat pump manufactures are shown in Table 1-20.

Table 1-20: Industrial heat pump penetrating barriers and its measures

		Barriers	Measures
(A)	1)	Lack of knowledge and experience with heat pump (*1) ・Knowledge accumulation of customer's heat pump is slight compared to boiler. ・Industrial customers concern about the risk of new technology.	Collecting and publishing information ・Stack of installation cases and good references is necessary for winning customer's confidence. (ex) Installation cases of industrial heat pumps, JEHC
	2)	Lack of data about heating demand and exhaust heat (*2) ・Industrial customers don't have data, especially flow rate. ・Even if they have data, they don't disclose the data for confidence. (*3)	Collecting data and development of affordable measurement system. ・Collecting data about heating demand and waste heat. ・Development of inexpensive and non-insert flow meter. ・Sharing information about industrial heating process.
	3)	Lack of engineering company specialized on industrial HP ・Installing a heat pump on an industrial process is not easy for more complex system than on commercial equipment and for securing quality of product. ・Spacing	・Education ・Permanent demonstration place for customer's understanding and help desk
(B)	4)	Limitation of achievable temperature by heat pump ・Most of the achievable temperatures are limited to 90°C. (*4) ・This is just a little share of industrial heat demand.	Development of higher temperature heat pump ・Development of new working fluid, expansion energy recovery, oil-free compressor, etc. (*5) ・Further actual survey of "real" heat demand is also needed.(*6)
	5)	Gap between heating demand and waste heat ・The use of heat pump as waste heat recovery is a skillful use, but this causes temporal and spatial gap between heating demand and waste heat.	Self-heat recovery and thermal storage ・Exhaust heat recovery is important, not waste heat recovery. (*7) ・For applying heat pump as self-heat recovery, not only survey of heating demand but also survey of exhaust heat is needed. ・High temperature heat storage is also needed.
(C)	6)	Long pay back periods (*8) ・Application of industrial heat pump can often achieve negative life cycle cost. ・But most of industrial customers hope short pay back periods of than 2 or 3 years.	Reduction of cost and cost leveling ・Reduction of initial cost by market expansion ・Reduction of running cost by higher efficiency ・Cost leveling by change of retailing, including leasing (*9) ・Introduction of new investment indicators (*10)
	7)	Hidden costs ・There are hidden costs which cannot be estimated for difficulty to measure: costs for searching new technologies and proceeding installation, etc.	Survey in each country.
(D)	8)	Inhibition of introduction by law, regulation, standard	Survey in each country.

(*1) Installing IHPs into industrial processes requires not only knowledge on the process itself but also knowledge on the application for IHPs. Unfortunately, many stakeholders do not have these combined knowledge essential to introduce IHPs in an appropriate way. (*2) Almost all companies may not have detailed information about production process heating and cooling demand which generated inside companies. They only have final energy consumption data. In order to install IHPs, it is necessary to measure and analyses deeply these demands to acquire actual information even though the investigation is expensive and time-consuming work. (*3) Since many companies do not disclose their own manufacturing processes information to other companies, the company does not publicize the actual state of heating and cooling demand inside the factory. Many installers have confidentiality agreements, and it is unlikely that valuable date such as the heat and mass balance within the factory will be made public. (*4) The technical challenge for IHPs is to enable to output higher temperature than conventional one. Almost of all application examples show that the maximum output temperature is limited below 65 degree Celsius. (*5) To raise the output temperature, there are many issues to be solved, for example, finding suitable refrigerant, and developing high thermal resist compressor and so on. Recently, good studies can find in the world, commercialization of IHP whose output temperature will exceed 150 degree Celsius will be expected near future. (*6) Factory managers prioritize product quality and are conservative against changes in production process temperature. By clarifying the relationship between the quality and the temperature, if the process temperature can be changed to the temperature suitable for the heat pump, there is a possibility of energy saving. (*7) The exhaust heat released immediately after the production process has little gap between time and space from the production process. (*8) Investment cost of heat pump is higher than that of fossil fuel burners. Many companies expect shorter payback period than three years. (*9) It is required to establish business without subsidy. (*10) Some companies accept longer payback period more than five years if some kind of return can be expected. Here, the return may include social reliability, responding to environmental regulations, improving work environment and so on. In technical speaking, it is necessary to develop IHPs that have extra high COP and long-term reliability.

4.3 Working fluids for IHP

4.3.1 Kigali Amendment

Fluorocarbons are widely used as a working fluid for heat pumps in the world. In 1987, with the entry into force of the Montreal Protocol to prevent the destruction of the ozone layer, the phase out of CFCs (R11, R12, R502, and so on) and HCFCs (R23, R22, R125, and so on) were decided. The protocol required that the production of CFCs must be discontinued by 1996 and that of HCFCs must be discontinued by 2020 in developed countries (in developing countries by 2015 and 2030, respectively).

In 2016, with the Kigali Amendment to mitigate global warming, the phase down (gradual reduction in production) of HFCs, which are substitutes for CFCs and HCFCs, was decided. In the Amendment, it is required that the production of HFCs should be reduced up to 15% down in 2019-2022 from that of 2016 (baseline) for developed countries and in 2029-2033 or 2031-2035 for developing countries.

In Japan, the Fluorocarbon Emission Control Law was formulated in April 2015, and the Global Warming Prevention Measures Plan was formulated in May 2016. Beginning March 2018, focusing on the reduction of HFCs, inspection obligations were imposed once every five years for equipment with a compressor output of 7.5 kW or more. Owing to these changes in circumstances, recovery of HFCs and development of new working fluids have become an urgent task.

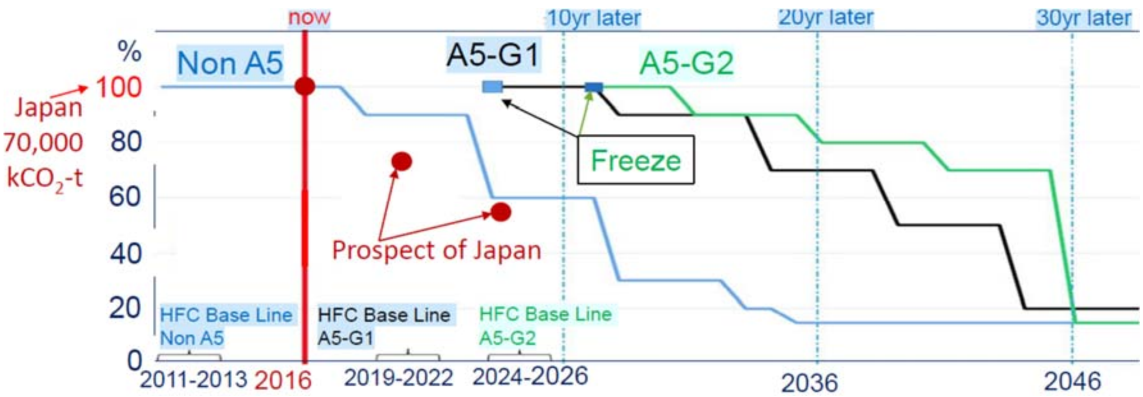


Figure 1-22: HFC phase down schedule under Kigali amendment [METI, 2017]

4.3.2 Alternatives of Working Fluids

R32 is one of the substitutes for R410A and has a lower GWP than R410A. The GWP of R32 and R410A is 675 and 2090 (IPCC 4th report), respectively. For the first time in the world, Japanese manufacturers developed and commercialized RACs and some PACs using R32 as a refrigerant.

Hydro fluoro olefins (HFOs) have been developed recently. HFOs have double bonds and are easy to decompose in the atmosphere, and they have lower GWP than HFCs. HFOs are not only used as a single substance but also as a mixture component. Some HFOs have weak flammability.

Natural working fluids, for example, CO_2 (R744), ammonia (R717) and hydro carbons (HC, isobutane (R600a) and propane (R290), are also types of low GWP working fluids.

R744 is beginning to penetrate the market as a working fluid for the heat pump water heater and industrial refrigerator. In Japan, cumulative shipments of ECOCUTE, a household heat pump water heater, exceeded 5 million units by 2016. In Europe, many refrigerators were installed. Two types of commercial CO_2 heat pumps are available in Japan. One can produce hot water, 90 °C maximum. The other can produce hot air, 120 °C maximum. The next challenges are enlargement of the capacity, enhancement of the efficiency, and decreased initial cost. **HCs** are highly flammable although they are easy to replace and have high performance. **R717** has toxicity. These working fluid challenges are the purview of safety and refrigerant.

The MVR system has attracted attention as a highly efficient steam latent heat recovery system in high temperature processes. The system is mainly applied to distillation and concentration processes, and re-compressed steam (=water, R718) is used as a heating medium (working fluid). The system is expected to gain popularity because it is a system that enhances energy conservation as well as global warming countermeasures.

4.3.3 Major countermeasures against HFC reduction

In many industrial processes, a heating temperature between 90 and 120 °C is often required. At the same time, the typical waste (or exhaust) heat temperature is 30 to 60 °C. If these waste heats can be utilized with a heat pump, attractive improvement in energy consumption intensity (kWh/production) can be expected.

HFCs, which are most commonly used as working fluids, are limited to a supply temperature of 80 °C. Further research and development of working fluids is required in the temperature range of 100 °C or higher. For IHPs, R134a, R245fa, R717, R744, HCs, etc., are used. However, HFCs (R-134a and R-245fa), excluding R-744 which has extremely low GWP and R-717 and HCs which are highly flammable, have large GWP (1430 and 1030, respectively). HFCs will be limited in terms of prevention of global warming. Therefore, low GWP substitutes need to be developed.

Currently, R1234yf and R1234ze(E) are promising as substitutes for R134a. R1234ze(Z), R1233zd(E), and R1224yd(Z) are listed as alternatives for R245fa. In addition, the maximum supply temperature of R245fa is 120 °C, but R1336mzz(Z) is attracting attention because of its applicable temperature of 150 °C. Table 1-21 shows basic characteristics of present and future working fluids.

Table 1-21: Basic characteristics of refrigerants for IHP application

Refrigerant	**R134a**	**R1234yf**	**R1234ze(E)**	**R450A**	**R513A**	**R513B**	**R454C**
Series	**HFC**	**HFO**	**HFO**	**HFC +HFO**	**HFC +HFO**	**HFC +HFO**	**HFC +HFO**
Composition, %							
R134a	100	-	-	42	44	41.5	
R32							21.5
R1234yf	-	100	-	-	56	58.5	78.5
R1234ze(E)	-	-	100	58	-	-	
ODP	0	0	0	0	0	0	0
GWP	1,300	< 1	< 1	547	573	540	146

Safety	A1	A2L	A2L	A1	A1	A1	A2L
Boiling Temperature, °C	-26.1	-29.5	-19.0	-23.6	-29.2	-29.2	-45.9
Critical Temperature, °C	101.1	94.7	109.4	104.4	96.5	95.5	82.4
Critical Pressure, Mpa	4.06	3.38	3.63	3.82	3.77	3.66	
Temperature glide, K	0	0	0	0.8	0	0	6

Refrigerant	R245fa	R1234ze(Z)	R1233zd(E)	R1224yd(Z)	R1336mzz(Z)
Series	HFC	HFO	HCFO	HCFO	HFO
ODP	0	0	~0	~0	0
GWP	858	< 1	< 10	< 1	< 10
Safety	B1	A2L	A1	A1	A1
Boiling Temperature, °C	15.1	9.7	18.3	15	33.4
Critical Temperature, °C	154.0	150.1	165.6	156.0	171.3
Critical Pressure, Mpa	3.65	3.53	3.62	3.38	2.90

4.3.4 Newly commercialized IHPs

At early 2018, two Japanese manufacturers independently announced that new industrial heat pump that use a low GWP refrigerant, will be commercialized within 2018. These IHPs are suitable for maintaining water or air temperature at a high temperature.

4.3.4.1 MHI Thermal Systems with a low-GWP refrigerant of R454C

Steam boilers fired by fossil fuels are widely used to create the hot water required in factories for removal of greases, cleaning of parts, etc. Recently, heat pumps have become increasingly prevalent owing to their contribution to energy saving enabled by their outstanding efficiency. The heat pumps available to date, however, use refrigerants with GWP values in a range of 1,430 to 2,090 times higher than carbon dioxide, and along with enforcement of the newly enacted Law Concerning the Discharge and Control of Fluorocarbons(*1), calls had been raised for the development of refrigerants with lower GWP values.

(*1) The Law took effect on April 1, 2015 as a revision of the earlier Law Concerning the Recovery and Destruction of Fluorocarbons. The new legislation mandates proper action to ensure against fluorocarbon leakage throughout all processes, and also calls for conversion to substitute fluorocarbons having a low GWP.

Mitsubishi Heavy Industries (MHI) Thermal Systems, Ltd. and Chubu Electric Power Co, Inc. announced that they have jointly developed the “Q-ton Circulation,” an air-source circulation heat pump(*2) engineered for use in factories at February 27, 2018 in Tokyo. The Q-ton Circulation reduces environmental impact significantly through adoption of the R454C, a refrigerant that features a GWP approximately one-tenth previously available refrigerants for the first time in Japan. It is also the industry's first heat pump of its type capable of heating water to 75°C amid an outside temperature as low as -20°C. The Q-ton Circulation will be marketed by MHI Thermal Systems for sale in Japan from August 2018. [MHI, 2018]

(*2) Air-source circulation heat pump: a heat pump that produces hot water by absorbing heat from the atmosphere.

The Q-ton Circulation system has the following advantageous characteristics;

1. Significant reduction in environmental impact through first adoption in Japan of low-GWP refrigerant

The Q-ton Circulation reduces environmental impact substantially through adoption, for the first time in Japan, of the R454C (GWP 146), a refrigerant that meets GWP clearance requirements (150) already in force in Europe.

2. World's first heat pump with capacity to produce hot water up to 75 °C amid an outside temperature down to -20 °C

Adoption of a two-stage compression refrigeration cycle prevents reduction in the hot water temperature normally caused by a low outside temperature. Water heated to 75°C can be supplied throughout an outdoor temperature range of -20°C to 43°C, to respond to year-round hot water needs in a factory.

3. Significant energy savings

Optimal engineering of the refrigeration cycle (optimization of pipe diameter etc.) has enabled the achievement of outstanding energy efficiency (COP(*3) 3.3) as a circulation type heat pump. When adopted in place of a factory boiler, for example, annual running costs can be cut by approximately 67%(*4).

(*3) Coefficient of performance: an index indicating the energy consumption efficiency of a heat source system. The higher the COP reading, the higher is the level of energy-saving performance. COP is calculated as heating capacity (kW) devided by power consumption (kW), where power consumption refers to the power consumed by the heat source unit. COP readings do not include power consumed by externally installed circulation pumps. The Q-ton Circulation's COP of 3.3 is the value under the following conditions: external temperature 25°C (relative humidity: 70%), water inlet temperature 60°C, and outlet temperature 65°C.

(*4) Refers to reduction when the Q-ton Circulation is installed outside for a process previously employing a gas boiler system with an overall efficiency of 50%. Reduction varies according to actual operation conditions.

4. Swift provision of after-sale service through use of IoT technology

Round-the-clock remote monitoring of the Q-ton Circulation's operating status will be available through "M-ACCESS," MHI Thermal Systems' proprietary Internet access platform. This will enable speedy servicing in the event of a system malfunction.

4.3.4.2 Mayekawa MFG with a non-fluorocarbon refrigerant of CO_2(R744)

HFO refrigerants with low GWP were newly identified as "specific inert gas" as a result of the revision of the regulation of "the High Pressure Gas Safety Act" in November 2016 and the products using HFO refrigerants are being introduced in the market.

In response to this background, MAYEKAWA MFG. CO., LTD. (hereinafter referred to as MAYEKAWA) first commercialized a "low GWP circulating heating thermal heat pump" using HFO refrigerant in Japan. Also MAYEKAWA will ship out from Feb. in 2018. MAYEKAWA launched the “CO_2 Hot Air Production System, Eco Sirocco” which uses CO_2 refrigerant and generates heat up to 120 °C by the heat pump in 2009. From the launch, MAYEKAWA has accumulated achievement in introducing and switching from steam boiler using fossil fuel to heat pump in printing stations and drying stages of various manufacturing industries. Since it was possible to apply only single heating with a temperature difference of 50 °C or more, MAYEKAWA received many requests from customers for development of circulation heating heat pump.

MAYEKAWA announced that they would start selling "circulating heating type heat pump" which can supply heat up to maximum 85 °C and uses low GWP HFO refrigerant from February 2018 [Mayekawa, 2018].

Figure 1-23: Performance test

MAYEKAWA plan to ship the first machine for domestic automotive-related affiliates in 2018, and as a result MAYEKAWA will strengthen sales for hot rooms, paint drying lines, and other processes that are requiring drying at 50 to 85 °C. In order to respond optimally to various operating conditions such as air heating temperature and air flow rate required in production line, this will be made to order.

1. Provide maximum temperature of 85 °C without burning
Since the heat pump system is adopted, it reduces CO_2 emissions by approximately 30% compared to boiler and other heating methods using fuels. Also, since there is no combustion process, nitrogen oxide (NO_x) does not occur.

2. Circulation heating with small temperature difference (5 to 10 °C)
For example, it can be heated at 5 °C when the air inlet temperature is 65 °C, and heat supply at 70 °C is possible.

3. High energy efficiency and high economic efficiency
Energy consumption efficiency (overall COP(*5)) is 3.5 when cold / hot heat is used at the same time. Running costs can be reduced by about 40%, and CO_2 emissions can be reduced by about 30%.

(*5) Overall COP: an index indicating the energy consumption efficiency. It is calculated as heating capacity (kW) plus cooling capacity (kW) devided by power consumption (kW). The COP of 3.5 is the value under the following conditions: the inlet air temperature is 63 °C, the outlet air temperature is 70 °C, and the heat source water inlet temperature is 14 °C.

4. Use non-fluorocarbon HFO refrigerant with low GWP and excellent high temperature characteristics

The ODP (Ozone depletion potential) of the non-fluorocarbon refrigerant is 0, and the GWP is below 1 to 4, based on IPCC Fifth Assessment Report (2013), Integral value is 100 years.

5 Further Activities for IHP application

5.1 Research and development for IHP application

- R&D of IHPs for high temperature and a large capacity -

The manufacturing process energy saving technology is enumerated, and an industrial heat pump is accounted to be one of the main technologies in "Energy conservation technology strategy 2016" of the Ministry of Economy, Trade and Industry in Japan. Moreover, the next generation type heat pump system is specified for a key technology to contribute to energy conservation as the individual segment in industry, building, and transportation sections.

In the industrial sector, the heat pump as a boiler substitute is an important technology in terms of CO_2 emission reduction and energy saving, but it is necessary to be able to generate high temperature heat of approximately 180 °C.

Related technologies include steam generation technology using waste heat, simultaneous supply of cold and steam, air heat source steam generation technology, high efficiency at circulating heating, development and application technology of high temperature working medium, compressor, heat exchangers, expansion power recovery, etc., and a wide range of technical development is required.

In NEDO's business, several groups are engaged in R&D aimed at high temperature output heat pumps. In the strategic energy-saving technological innovation program, the Fuji Electric and Anest Iwata Group has developed a steam output heat pump that recovers exhausted hot water after using the steam in factories and regenerates it to 150 °C steam. They aim to realize a high-efficiency cycle using a low environmental impact refrigerant in a coaxial scroll dual compression system.

In the research and development projects about the utilization of unutilized thermal energy, the research association TherMAT is a promoting research and development of a high-temperature output steam compressed heat pump aiming at a heating temperature of 200 °C and COP of 3.5 or higher, which can replace the conventional boiler as the effective heating system using the high-temperature heat pump. A number of companies, universities, and research institutes are conducting joint research on the project; for example, Mayekawa MFG, Waseda University Group. As a result, we have trial-produced a turbo compressor that achieves 70% heat insulation efficiency with oil free, ultra-high-speed rotation.

Mitsubishi Heavy Industries Thermal Systems, Mitsubishi Heavy Industries, Central Glass, National Institute of Advanced Industrial Science and Technology, Kyushu University, and Saga University Group also aim to achieve higher temperatures by applying low GWP refrigerant to a two-stage compression bleed cycle for similar targets. In addition, in the projects aiming to expand the usable temperature range of waste heat, we will also advance the development of an absorption type refrigerating machine that can utilize unused heat at a lower temperature than before.

Hitachi Johnson Controls Air Conditioning Co., Ltd., Hitachi, Ltd., and Hachinohe Institute of Technology Group developed a single-effect double lift absorption chiller that adopted the double lift cycle and parallel absorption flow method. In the conventional absorption chiller, it can only use heat up to 75 °C (temperature difference of 20 °C) for hot water waste heat at 95 °C. In the developed system, it was possible to use heat up to 51 °C (temperature difference of 44 °C) in the lower temperature range.

5.2 Regulation

- Conservation of energy system for spread promotion -

Regarding Japan's energy demand, the Japanese government expects significant energy efficiency improvement by 2030 FY. It is described in the "**long-term energy supply and demand outlook (energy mix)**" established by Ministry of Economy, Trade and Industry. More thorough energy conservation measures are required like those employed during the time of the oil crisis.

There is the "**Industrial top runner system (bench mark system)**" that evaluates the match situation of entrepreneur's energy conservation by using a common index to the type of business, aims at the achievement of the target (level that should be achieved) by each entrepreneur, and advances the match of energy conservation as an energy conservation measure on which it works in the country.

Initially, the system was introduced mainly in the manufacturing industry. In April 2016, it was introduced to the convenience store industry, and beginning in April 2017 the introduction expanded to hotels and department stores. In the future, introduction into distribution and service businesses such as food supermarkets, rental offices, shopping centers, etc. will be promoted.

Moreover, the classification divides all entrepreneurs into four stages in the "**Entrepreneur classification evaluation system (SABC evaluation system)**" introduced in 2016 FY according to the match situation of energy conservation. The aim is to improve the entrepreneur’s motivational desire for energy conservation. In addition, "**Unused heat use system**" that aims at entrepreneur's improved motivation is applied from the periodic report in fiscal year 2017. This is a system evaluated as an energy conservation approach when the unused heat generated at other entrepreneurs' factories, etc., is bought, and used at its own factory, etc. Concretely, the unused calorie bought from the amount of the energy use can be subtracted when the unit requirement is calculated, and the improvement of the unit requirement becomes possible. For instance, the rejection heat that occurs from the exhaust, and the production facility of the boiler, and the power generating machine becomes the object for unused heat. In addition, the energy conservation measure is held from both sides of the system and support as a supplementary system is installed for ZEB (the net energy 0 building) that the building in which it aimed to cover the energy consumed during year by renewable energy and is the house, ZEH (the net energy zero house), and the next generation car.

5.3 Subsidies

Aiming to promote energy saving in the industrial and commercial sectors, the government introduced a support project to encourage investment in energy-saving equipment including industrial heat pumps.

Project name

Support Grants to Promote Energy Saving Investments in 2018FY (Energy Use Rationalization, Etc., Business Operators Support Project) [SII, 2018]

Project goals

In the face of the rapidly growing need to resolve global environmental problems, Japan has achieved a level of energy saving ranked among the highest in the world, as for many years.

Japan has been working to promote investment in energy-saving systems and to rationalize energy management. However, to realize an energy savings target of approximately 50.3 million kL, as per the Long-Term Energy Supply and Demand Outlook of July, 2015, it will be necessary to encourage investment in energy-saving equipment in the industrial and commercial sectors. This project aims to promote energy saving in each sector, thereby building a stable and appropriate energy supply and demand structure adapted to the domestic and foreign economic and social environments. The project will subsidize part of the costs of introducing high-energy saving performance machinery and systems that contribute to peak electric power countermeasures from several initiatives intended to rationalize energy use and level the supply and demand for electricity (below, “subsidized projects”).

FY2018 Budget

Approximately 19 billion yen

Subsidized projects

The following projects, which are conducted in factories and business premises that perform integrated energy management are subsidized:

(a) Energy-saving countermeasure projects:

Projects that conserve energy by replacing or renovating energy saving systems or by newly installing energy management systems (EMS) with measurement, visualization, and similar functions.

(b) Peak electric power countermeasure projects:

Projects that reduce electric power usage during electric power supply- and demand-leveling periods (i.e., peak electric power time periods) by installing new storage batteries, thermal storage systems, and in-house power generation systems.

(c) Energy management projects:

Projects that conduct more effective energy-saving countermeasures by letting contracts with energy management business operators and energy management support services that use EMS equipped with measurement, visualization, similar functions registered with Sustainable open Innovation Initiative (SII), and energy management business operators selected from web-page information.

From beginning in FY2018, it will be possible to apply for subsidization of projects that save energy by reducing the load on existing systems under the category of process improvement like the following activities; (1) using exhaust heat and other surplus energies, (2) improving existing equipment and equipping it with inverters, (3) introducing heat pumps to lower the load on existing boilers, etc. Industrial heat pumps are also covered, and it will be possible to apply for project subsidization to replace boilers and other existing equipment even when additional industrial-use heat pumps are being installed.

Energy management business subsidization rate

1/3 or 1/2

6 Summary

The activity of Task 2 is to select the best practice of industry based on the samples of good practices investigated in Task 1. We developed the multiple criteria related to the market potential of IHPs, technological advantages of IHPs, and effects of installation to solve complex problems of decision making. Good practices are scored by the relative merit of the multiple criteria. The multiple criteria are also structured to decide the weight of criteria and sub-criteria by the analytic hierarchy process. The best practice is selected by the weighted value obtained from the product of score and weight of the multiple criteria for good practices in each industry.

Three samples are selected as the best practice: a sample of No. 2 titled “Simultaneous heating & cooling system in food production line for” the food industry, a sample of No. 21 titled “Simultaneous heating & cooling in cutting and cleaning process” for the machinery industry, and a sample of No. 32 titled “Introduction of hot heat pump with hot gas source in dry laminating process of package film” for the chemical industry. We describe the detailed information on the three best practices selected by the evaluation method.

IHPs are expected to be widely installed in industry processes because a large amount of steam or heat in the conventional boiler system is actually lost before it is used. However, some barriers need to be overcome to successfully apply heat pumps for each industrial sector. The barriers are categorized into eight different factors and explained in detail.

Fluorocarbons are widely used as a working fluid for the heat pumps used in industries. The Montreal Protocol to prevent the destruction of the ozone layer required that the production of CFCs must be discontinued by 1996 and that of HCFCs must be discontinued by 2020 in developed countries (in developing countries by 2015 and 2030, respectively). In 2016, with the Kigali Revise to mitigate global warming, the phase down (gradual reduction in production) of HFCs, which are substitutes for CFCs and HCFCs, was decided. We introduced the Japanese policy on refrigerant regulation of the Fluorocarbon Emission Control Law as well as the Global Warming Prevention Measures Plan formulated in 2016.

In the industrial sector, the heat pump as a boiler substitute is an important technology in terms of CO_2 emission reduction and energy saving, but it is necessary to be able to generate high temperature heat of approximately 180 °C. We introduced the Japanese R&D on industrial heat pumps such as waste heat recovery technology, simultaneous supply of cold and steam, air heat source steam generation technology, high efficiency circulating heating, development and application technology of high temperature working medium, compressors, heat exchangers, expansion power recovery, etc.

In Task 2, the best practice of industry is selected for providing stakeholder policy makers with knowledge and information about IHPs. We also described future activities on R&D of IHP technologies as well as existing governmental support to enhance the utilization of heat pumps in industries in Japan.

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