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The Key Points of Efficient Application of Ground Source Heat Pump System

Along with the encouragement and support of policy, increasing the scale of ground source heat pump (GSHP) project, the application area of GSHP system is expanding in China. However, the operation of some existing GSHP projects is poor. The effect of energy saving is not obvious due to various reasons existed in the design, construction and operation. How to improve the efficiency of the heat pump system has aroused wide concern. The key points of efficient application of GSHP system is discussed in this paper from the viewpoint of system theory. It analyzes the low temperature heat source, heat pump units, transmission and distribution system, auxiliary system, user terminal equipment.

An inside story behind the advent of “Eco Cute” CO2 heat pump water heater for residential use

More than ten years have passed since the “Eco Cute” CO2 heat pump water heater for residential use was commercialized in May 2001 in Japan through the collaborative R&D including CRIEPI. Its cumulative shipments are over 4.6 million at the end of March 2015. There were two projects involving hot water supply heat pumps prior to the development of the Eco Cute in CRIEPI, though neither went into commercial production. In this paper, the history and technical aspects of the advent of the Eco Cute, including the former two projects, are introduced.

GENERAL

■HVAC&R Japan 2016 Preview
‘A Look at Heating and Cooling Technologies for an Ideal-Temperature Future’

Japan

The Japan Refrigeration and Air Conditioning Industry Association (JRAIA) is slated to hold the 39th Heating, Ventilating, Air Conditioning and Refrigerating Expo (HVAC&R Japan 2016) over the four-day period of February 23-26, 2016, at Tokyo Big Sight Exhibition Center in Japan.

HVAC&R Japan has played a critically important role as Japan's only specialized trade fair in the HVAC&R industry over the past half-century, providing public relations opportunities for the industry as well as a venue showcasing corporate technology developments and new products. The exhibition itself has developed over the years in tandem with the industry. During this period, Japan's HVAC&R equipment industry has become one of the world's technological leaders, particularly in the field of highly efficient heat pump technology.

HVAC&R Japan 2016 is to focus on four key themes: energy, environment, temperature, and technology. Among these four themes, JRAIA believes that temperature is critically important in showcasing corporate activities focused on this technology– that connects the past, the present, and the future. For this reason, JRAIA chose 'A Look at Heating and Cooling Technologies for an Ideal-Temperature Future' as the overarching theme of the event.

HVAC&R Japan features multiple parallel events: not only does it showcase world leading technologies as well as the latest equipment and systems in the environmental field all in one place, it also offers various seminars and enables visitors to gain insight into new products and trends provided by exhibitors. HVAC&R Japan is designed to facilitate business opportunities for exhibiting companies and to provide an opportunity for exhibitors to disseminate information on their cutting-edge technologies to the world.

Source; JARN ,January 25, 2016

■ENEX2016 Held in Conjunction with Two Other Energy Expos

Japan

The ENEX2016, concurrently with the Smart Energy Japan 2016 and the New Power and Energy Expo that was held for the first time this year, took place on January 27-29 at the East Halls of Tokyo Big Sight. The number of visitors during the three days reached 48,514 according to the organizer.

ENEX is a comprehensive exhibition in the field of energy conservation and new energy. A large number of business operators and officials from national and local governments wishing to promote energy conservation and to rationalize energy use visited the exhibition.

Smart Energy Japan is a professional exhibition in the field of design and development concerning energy management. It features all types of elemental technology such as technologies for energy conservation and power control, information communication, and smart networks.

New Power and Energy Expo is a professional exhibition that covers a full range of all devices, systems, and services concerning the power retail business, including power supply and retail services in view of the introduction of full liberalization of the retail electricity market in Japan from April 2016.

The exhibitions focused on the demand, supply, and management aspects, all of which are necessary to effectively utilize supply and demand and to facilitate the efficient use of energy in the future.

The three exhibitions were held under the auspices of an overarching concept supporting energy conservation and power saving for all energy consumers, promoting rationalization of energy use, and offering opportunities for the creation of new services resulting in energy conservation and new power businesses.

In the context of full liberalization of electricity retailing staring in April this year in Japan, all leading electric power, gas and new electricity related companies, including Tokyo Electric Power, Tokyo Gas, Chubu Electric Power, and Kanden Energy Solution, showcased their products and services.

The main exhibits at the New Power and Energy Expo 2016 included electric power supply services, power supply/demand management systems, demand response services, power storage systems, and electric power business backup consulting.

As in the past, the 'Energy Conservation Grand Prize' winning products were also exhibited in the Awards Corner.

Source; JARN ,February 25, 2016

■ National Society of HVAC and related special committee was held in Nanjing, Jiangsu Province

China

On December 15-16 2015, the series of National Society of HVAC (HVAC Branch of the Architectural Society of China, China Institute of Refrigeration Air-conditioning professional committee) events were successfully held in Nanjing, Jiangsu Province.

The event is divided into two parts, one is to arrange the establishment of Heat Pump Professional Committee, Air-conditioning Professional Committee, and the Youth Committee, according to the National Institute of HVAC air conditioning eighth work of the Council; the second is organized by the National Academic heat pump technology in the same period will, air-conditioning technology development forum, Youth Science and technology Forum three forums.

Xu Wei, served as the chairman of the heat pump as the committee, and Professor Ma Zuiliang from Harbin Institute of Technology served as honorary director.

The establishment of each special committee of National Society of HVAC air conditioning, can not only accelerate the improvement organization building, but also promote and facilitate the professional of the HVAC industry an important manifestation.

Policy

■The industrial standard "Technical specifications for cool storage air conditioning system" JGJ158- 2008 was formally implemented

China

The industrial standard "Technical specifications for cool storage air conditioning system" JGJ158- 2008, was formally implemented in 2008.

This standard has played an important role in the TES field in China during last 7 years.

On this April, the revision work of this standard has been formally started. 26 units took part in the revision work. The establishment of the working group and preparation of the first working group meeting was held in Beijing on April 13, 2015, the leader of the Ministry of Housing and Urban-Rural Development Institute standard quota, editor of China Academy of Building Research Unit and Construction Group Co., Ltd. The leader of Qingdao Bohai, the Housing and Urban construction Department of building environment and Energy Conservation standardization technical Committee standards management staff and all members of the group prepared a total of 40 people attended the meeting.

The revision work will be completed by the end of 2016.

Market

■Energy Conservation Grand Prize Ceremony for 2015

Japan

At ENEX 2016 held at the Tokyo Big Sight convention center at the end of January, a ceremony to award the 2015 Energy Conservation Grand Prize for excellent energy-efficient equipment was held. The prize is organized by the Energy Conservation Center, Japan (ECCJ), with the aims of contributing to increased awareness, activities, and steps toward saving energy and promoting the use of energy-saving products.

Daikin—received the Minister Prize of Economic, Trade and Industry, the highest prize, for its 'Promotion of energy conservation through worldwide expansion of high efficiency of HFC-32 air conditioners.' The company was highly recognized for having contributed to the prevention of warming on a global scale by adopting HFC-32 refrigerant, which can reduce equipment's impact on global warming.

Daikin also received the Chairman Prize of ECCJ for its VRF air conditioners. These VRFs reduce annual power consumption by adopting a new scroll compressor that achieves higher efficiency during low-load operation as well as new technology that automatically controls refrigerant temperature according to the load during cooling and heating operation. The technologies incorporated into this series can contribute to the realization of net zero energy buildings (ZEBs).

Mitsubishi Electric—received the Minister Prize of Economic, Trade and Industry, the highest prize, for its room air conditioners (RACs) in the Kirigamine Advance FZ series. These innovative, state-of-the-art air conditioners make high energy-savings compatible with comfort by completely redesigning the indoor unit structure for the first time in about 50 years and incorporating the world's first personal twin flow fans.

Panasonic—received the Chairman Prize of ECCJ for its WX series of air conditioners featuring the company's Econavi function and its cooling unit that uses photovoltaic power generation.

The WX series of RACs provides individualized air conditioning by adopting a technology that, by means of a thermal image sensor, can detect the heat or cold felt by each user. They also realize continuous heating operation without an electric heater by collecting the heat ejected from the outdoor unit's compressor in heat storage material and effectively utilizing it during defrost operation.

The cooling unit incorporates Panasonic Ecology Systems' sensible resin heat exchange element and a high-efficiency brushless DC (BLDC) motor. Adopting this cooling unit to Daihen's power conditioner realizes efficient heat exchange between low-temperature outside air and heated air inside the housing to cool the conditioner with less electric power while maintaining airtightness.

Hitachi Appliances—received the Chairman Prize of ECCJ for its large-capacity refrigerators in the Vacuum Chilled series. This series was highly rated for its energy-saving technologies, such as the industry's first multi-valve control, which makes energy savings compatible with the cooling power required to realize larger capacity.

Toshiba Carrier—received the Chairman Prize of ECCJ for its heat pump heat source units in the Universal Smart X3 series. The Universal Smart X series already received the Minister Prize of Economic, Trade and Industry for 2011. The second award this time was given in recognition of further energy savings and higher added value.

Source; JARN ,March 25, 2016

■ Japanese Manufacturers Keeping Pace with R32 Use in PACs

Japan

A leading edge knowledge hub for ductless air conditioner technology, the 39th Heating, Ventilating, Air Conditioning and Refrigerating Expo Japan (HVAC&R JAPAN) 2016 was held from February 23 to 26 at Tokyo Big Sight. HVAC&R JAPAN is organized biennially by the Japan Refrigerating and Air Conditioning Industry Association (JRAIA). This year's exhibition was the attracted 188 exhibitors and 27,383 visitors during the four-day event.

Although this exposition is not large in scale, the latest technologies and products in the field of HVAC&R are displayed. Major HVAC&R manufacturers exhibited a wide range of products for residential and commercial applications. Products intended for industrial uses also stood out.

At this year's exposition, almost all Japanese manufacturers exhibited packaged air conditioners (PACs) using the next-generation refrigerant R32. They focused on R32 PACs ranging from 3 hp to 6 hp for light commercial use. At the previous exposition held two years ago, Japanese manufacturers displayed models demonstrating that the manufacturers were keeping pace with R32 use in room air conditioners (PACs).

Source; JARN ,March 25, 2016

The Key Points of Efficient Application of Ground Source Heat Pump System

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ABSTRACT (Initial CAPS, 11-pt Arial font, bold)

Along with the encouragement and support of policy, increasing the scale of ground source heat pump (GSHP) project, the application area of GSHP system is expanding in China. However, the operation of some existing GSHP projects is poor. The effect of energy saving is not obvious due to various reasons existed in the design, construction and operation. How to improve the efficiency of the heat pump system has aroused wide concern. The key points of efficient application of GSHP system is discussed in this paper from the viewpoint of system theory. It analyzes the low temperature heat source, heat pump units, transmission and distribution system, auxiliary system, user terminal equipment.

KEY WORDS: Ground source heat pump (GSHP), Energy efficiency, Emission-reduction

INTRODUCTION

The maximum average concentration in 24h was 766 μg／m3. So, the pressure on energy saving and emission reduction was unprecedented. Under this background, the GSHP, as a kind of energy-saving technology, driven by the relevant policies in recent years, has acquired widespread application, the project size has been increasing rapidly simultaneously. Furthermore, some projects have already obtained successful results on energy conservation and emission reduction. While at the same time, due to a variety of reasons existed in the processes of preliminary scheme, design, construction, operation and final-period management, some problems have happened to part of the GSHP systems engineering which affected its normal use, even worse, part of the systems could not work. It directly lead to not only the waste of the owners' investment and the state's subsidies, but also the doubts for applying the GSHP system from the users or even the workers. Therefore, the improvement of the GSHP system energy efficiency makes its application a current concern. By participating in the design and test of a series of GSHP researches for investigation and analysis, we analyze several essential problems for the efficient application of GSHP system from the low temperature heat source to the user terminal system.

LOW TEMPERATURE HEAT SOURCE---ensure the heat balance of absorbing and releasing, avoid the accumulation

As the heat source in winter and heat sink in summer for the heat pump, the essence of soil is energy storage. The heat absorption and rejection of the heat exchanger depends on the heat transfer processes of both building system and soil source heat exchanger.

To get the cumulative total of the absorption and rejection of heat, we must do hourly coupling calculation for both heat transfer processes.

It is unreasonable to determine the number of boreholes by estimating heat transfer rate per meter during the system design process. Heat transfer rate per meter is obtained by the heat transferred which is tested by experiment in 48 hours divide the depth of borehole. The test results only represent the heat transfer rate under the condition that only run the test

borehole in a specific time period. So there are obvious deviations using such values to estimate the heat of absorbing and rejecting in the operating process of GSHP system. According to the new standards in GB50366-2005 (2009), the demand for soil thermal physical property test, through the test, we can obtain the complex thermal conductivity coefficient and the soil specific heat at local condition, the project is located by fitting calculation. It can be more close to the actual operation by employing these two parameters to calculate the absorbing and rejecting heat in GSHP system.
Finally, the arrangement of the boreholes is also important, it may decrease the thermal disturbance as the increase of the distance between each other. Therefore, it is positive to increase the distance of heat exchangers under the conditions which areas is allowed. For large-scale GSHP systems, the boreholes should be arranged by separated partitions. In the operation, it should supply energy in separated areas by turns. In this way, it's better for the long-term efficient operation.

UNIT CONTROLAND TRANSMISSION---improve the level of unit auto-control, optimize the hydraulic transmission system, reduce the heat loss

1) Improve the level of unit auto-control to ensure the system is also operated efficiently under partial load

The heat pump unit is the core equipment for the heat pump system. Various kinds of heat pump units can be chosen to satisfy the different types of heat pump systems. Almost every equipment manufacturer has produced the GSHP units. For GSHP, the water temperature of the borehole outlet in winter is below 15 ℃, the load demand is maximal while the temperature of the outlet water is lowest. The same problem also exists in summer. The heat pump units always focus on the max load conditions, most of time, the capacity of units is too large, and the efficiency is lower under partial load. To improve the efficiency of GSHP system, heat pump units should be decided by the end of the building load calculation hourly and coupling calculation for the ground heat exchangers, at the same time, according to the load frequency, choosing the higher COP heat pump units under the high frequency load.

2) Water distribution system should be designed scientifically and constructed rigorously

The GSHP system includes numerous ground heat exchangers, and the hydraulic transmission system is more complicated. So only the scientific design for the ground heat exchangers and rigorous construction can ensure the system's efficient operation. That means in the design process, the number, spacing and the effective depth of heat exchangers should be calculated scientifically for GSHP based on soil thermal physical parameters and meteorological parameters where the project is located, and meanwhile, a comprehensive detailed hydraulic balance calculation should be taken.
In the process of construction, the work should be finished strictly in accordance with the drawings combined the situation of construction, after the construction, the comprehensive hydraulic balance of debugging should be carried out.
From some current GSHP system, we find that the effective length of ground heat exchangers is reduced due to the poor construction condition.
Some other projects have no hydraulic balance of debugging after construction. The measured datas of a GSHP project is shown in Table 1. From the Table we can see that the flow doesn't increase as the numbers of heat exchangers, part of the heat exchanger in Area 2 is blocked.
In addition, the complexity of the ground heat exchange system needs more careful arguments for GSHP hydraulic system.
The selection of pumps and the settings of operation should be adapted to ground heat exchanger system, this is very important, especially for large-scale systems.

Some projects can take turns to use ground heat exchangers in separated areas if possible, at this time, the pump is chosen as the exchangers of each area. Frequency conversion of

pump should be taken in to reduce the system distribution energy consumption under partial load and in this way make the system's efficiency higher.
Besides, detailed hydraulic calculation, monitoring system, using the double pump like shown in Figure 1, etc. can be taken into consideration. Hydraulic transmission system aims to improve the flexibility of the adjustment and control, make it better to adapt to changes in system load, reduce the energy consumption of distribution system, and improve the energy efficiency of the system under the premise that the system is stable.

Table1 Buried side flow meter

Area	Number of Borehole	The flow (m^3/h)
Area 1	57	137
Area 2	80	115.6
Area 3	135	164.3
Area 4	215	212

Fig.1 Double pump hydraulic distribution system diagram

3) Energy loss of circuit headers should be avoided.

For more and more large-scale system, it is important to reduce the heat loss of system and ensure energy distributing efficiently to the users.
At present, in the design of large-scale GSHP system, circuit headers of ground heat exchangers which are considered in the condition of heat insulation [3] are not contained in the length of the heat exchanger.
However, in the actual project, circuit headers are all directly buried without thermal insulation. This part of the heat loss can be ignored in small-scale systems, but for the large-scale GSHP system, it can't be ignored.
Till now, there are few heat loss researches of circuit header for borehole system.
The author took one office building in Beijing as an example, carried out the simulation results on the energy loss problem of circuit headers and draw the conclusion that the energy loss of circuit headers in the different length in the winter did have effect on the unit COP, recommendations for horizontal headers in different length were also proposed [4]. For other projects in other places, the similar methods can be employed to obtain relevant conclusions.

3 AUXILIARY SYSTEM---The energy should be used according to the quality, adapted to local conditions

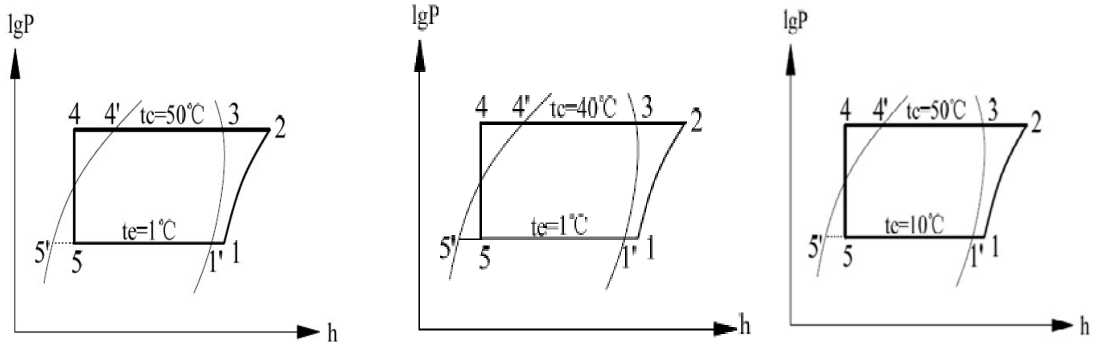
Auxiliary system is stetted to avoid the imbalance between absorption and rejection of heat on the low temperature reservoir of soil which is due to the user's deferent demanding for temperature.
It is effective to adapt to the variety of the areas which the heat pump of current soil source are applied to, and it's also an important part of the heat pump system for the hybrid soil source.

The key of realizing efficiently running of the heat pump system for the hybrid soil source is the energy should be used according to the quality and adjust measures to local conditions.

Users, who use the renewable energy such as solar energy and air source as the auxiliary system, can be considered according to actual operation condition, if the direct power of renewable energy cannot meet the user's demand, it can be used as a supplement of underground temperature field. While if the boiler or cold machine and cooling tower system is used as the auxiliary system, we should give priority to the users directly. In this way it can avoid the high-quality energy be used inefficiently due to putting back the high-quality energy to underground temperature field after heating or cooling.

4 THE USER TERMINAL SYSTEM—Select the appropriate terminal system "improving the cooling temperature and reducing the heating temperature".

In the ideal heat-pump cycle, improving the evaporating temperature or reducing condensing temperature will improve the COP value. The ideal heat pump cycle which uses several kinds of common refrigerants changes as Figure 2, the COP values will improve as shown in Table 2.



（a）the ideal heat pump cycle　（b）reduce the condensing temperature　（c）increase the vaporization point

Figure 2 the ideal heat pump cycle and the pressure enthalpy diagram after adjustment

According to the results, we can know that reducing heating water temperature in winter and increasing cooling water temperature in summer under the ideal conditions can improve the energy efficiency of the heat pump cycle significantly. In practical engineering applications, the EER is less than ideal conditions as a result of the heat pump cycle's irreversible process and friction loss. But under the two different conditions, changing the evaporating temperature and condensing temperature both enhance energy efficiency, this trend is unchanged. Therefore, we can obtain the direction for the optimization by analyzing this ideal cycle.

Table2 conditions COP calculation comparison table in the ideal

Refrigerant	the ideal heat pump cycle COP	reduce the condensing temperature COP	After reduce the condensing temperature Increase the percentage of COP	increase the vaporization point COP	increase the vaporization point increase the vaporization point COP
R22	4.46	5.96	33.6%	5.85	31.2%
R134a	4.44	5.98	34.7%	5.87	32.2%

R407C	4.26	5.82	36.7%	5.63	32.2%

We should take the low-temperature heating terminal equipment in winter and high-temperature cooling terminal equipment in summer actively. In general, conventional air-conditioning mode will bring a series of new problems, while reducing winter heating temperature and increasing in summer temperature cooling, such as heat and moisture load cannot all be met with, etc.
Currently, the application of independent temperature-humidity control air conditioning system provides a new opportunity for the application of highly efficient heat pump terminal devices.
The heat pump system can only supply the sensible heat, operate safely and keep a higher level of energy efficiency. Heat pump system should take priority of the "High temperature cooling and Low temperature heating terminal system devices".

5 OPERATION AND MANAGEMENT--Strengthen the operation of monitoring, management and maintenance

GSHP system should not only maintain long-term efficient operation, but also strengthen the monitoring and management and maintenance.
Through setting the monitoring system, the soil temperature, water temperature and flow of the GSHP system should be monitored.
It is convenient to check the heat exchange capacity of the system which has run for years, and adjustment operation strategy appropriately according to monitoring data.
Especially for hybrid GSHP system, by monitoring and timely adjusting supplements of the auxiliary energy immediately can not only ensure the effective application of auxiliary energy and energy supply of the terminal, but also make the soil source system achieve long-term efficient operation.
We should choose a reasonable position for the monitoring device buried, which should be as close to the regional centers as well, then the values can be measured objectively and reflect the actual temperature of the soil conditions. If the monitoring devices are disposed in the outer region of the heat exchanger as inconvenient location for construction and some other reasons, the value of the testing temperature is greatly reduced, which cannot reflect the actual situation accurately.
The management of electricity systems and hydraulic transmission and distribution systems should be strengthened in order to avoid local faults which may affect the whole system operation.
The daily maintenance is important, and particular attention should be paid on the drainage of the distributed-centralized water chambers. Especially after rain and snow, more attention should be drawn on maintenance of the valves and insulating layers. Drainage should avoid creating new point of energy loss.

CONCLUSION

GSHP system is an effective way of using renewable energy , the effective application depends on reliable thermal physical properties of test data, the scientific simulation analysis, systematic design process, the correct construction debugging and effective management and maintenance. We hope that the analysis in this article can draw the attention of the professionals, promote the effective application of GSHP and make the GSHP system give full play to its role in energy saving and emission reduction.

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An inside story behind the advent of "Eco Cute" CO_2 heat pump water heater for residential use

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Summary

More than ten years have passed since the "Eco Cute" CO_2 heat pump water heater for residential use was commercialized in May 2001 in Japan through the collaborative R&D including CRIEPI. Its cumulative shipments are over 4.6 million at the end of March 2015. There were two projects involving hot water supply heat pumps prior to the development of the Eco Cute in CRIEPI, though neither went into commercial production. In this paper, the history and technical aspects of the advent of the Eco Cute, including the former two projects, are introduced.

1. Introduction

More than ten years have passed since the "Eco Cute" CO_2 heat pump water heater for residential use was commercialized in May 2001 in Japan through the collaborative R&D of Tokyo Electric Power Company (TEPCO), Denso Corporation (DENSO) and Central Research Institute of Electric Power Industry (CRIEPI). It has become widespread by introduction of subsidy by Japanese government, market entry of new manufactures and growing interest in environmental problem. Its cumulative shipments are over 4.6 million at the end of March 2015 as shown in Fig. 1[1].
There were two projects involving hot water supply heat pumps prior to the development of the Eco Cute in our institute, CRIEPI, though neither went into commercial production. On this occasion, the history and technical aspects of the advent of the Eco Cute, including the former two projects, are introduced.

2. History of research & development of heat pumps in CRIEPI

The R&D activities of heat pumps in CRIEPI began when it was entrusted to a part of the Super Heat Pump development project, which was a national project and started in 1984. Because the heat pumps work on the same principle of the thermal power generation cycle, a staff member of the thermal power section who was senior to me was assigned to play a central role in this research project. The CRIEPI decided to hire a new employee for the project, which led to me being hired to join in 1986.
Not only to do the entrusted research but also to have started the original research in CRIEPI, the sector in which the introduction of a heat pump could bring about a large energy saving effect was investigated. As results, it was found that major energy savings were possible if a highly efficient heat pump could be developed and introduced for domestic tap water heating. The demand for hot tap water accounts for about 30% of residential final energy consumption, but most of this demand is met by direct combustion of fossil fuel.
Under such a circumstances, a new system named the "two-stage compression and cascade heating heat pump water heater (TS-HPWH)" was invented by my senior staffer based on his knowledge and experiences in the field of the thermal power generation cycle. This system was later issued as a patent of Japan.
For a normal refrigerant such as Fluorocarbon, water or air is heated by a refrigerant that condenses at a constant temperature on the high pressure side of the heating cycle. For this

reason, good efficiency can be gained if the heating temperature range is small, as seen in the cycle for air conditioning. On the other hand, for hot water supply, water of 10 °C needs to be heated up to 65 °C, thus requiring a heating process with a high temperature rise. Fig. 2 (a) shows the heating process wherein water at 65 °C is made by a simple heat pump cycle. As shown in the figure, there is a section in which low temperature water at about 20 °C is heated by condensing refrigerant at about 70 °C, which results in large loss. A heating temperature of about 30 °C suffices to heat the water at 20 °C.

While the TS-HPWH we had invented, it was intended to decrease the irreversible loss by preparing two condensation pressures through its two-stage compression. By doing so it could achieve proper heating suitable to the temperature level as shown Fig. 2(b). Next, whether this system could actually be put into practical use should have been examined, and what kind of elemental technology should have been adopted for it. On this account, an experimental apparatus of the system was manually fabricated as shown in Fig.3. Using this apparatus, feasibility of its cycle was verified and good results were obtained.

The collaborative R&D with electric power companies and a manufacturer was conducted from 1988 to 1992 for developing the air conditioning & hot water supply heat pump for residential use based on the TS-HPWH. The development progressed smoothly, evolved to actual field tests. Despite these efforts, this apparatus was not made into a commercial product. The reasons were lower hot water supply efficiency than expected and its unattractiveness in terms of price, size and so forth. Rather than a multifunctional heat pump, a heat pump equipped with only a hot water supply function was to be developed.

Having learnt the experience, the development of the TS-HPWH for business use in hotels and other facilities was conducted from 1990 to 1996. The prototype was made as shown in Fig.4. For commercializing it, the collaborative development with a manufacturer and a general contractor was done. In the collaboration, a basic system for business use was established and its elemental technology was developed. Unfortunately, the system was not commercialized because of issues surrounding Fluorocarbon. The developed system was very good from a technical standpoint, particularly because it was designed specifically for hot water supply. However, the development was underway at an inopportune time.

Thus, two collaborative developments were made but neither resulted in commercialization. Two younger colleagues joined us, so four employees engaged in the R&D project at the CRIEPI, with some funds being invested into the ongoing project. Accordingly, R&D of heat pumps was under increasing pressure in-house, being questioned as to the degree of progress of our research on the heat pump.

3. Investigation of natural refrigerants and encounter with CO2 refrigerant

One of the main reasons for the failure of the commercialization of the two-stage compression system for business use was an issue surrounding the use of Fluorocarbon. CFC12 was used for the heat pump. At that time, the refrigerants of the HFC family had become promising alternatives to the conventional refrigerants in Japan and the United States. In Europe, the move was toward examining natural refrigerants. Considering these facts, our investigation was started in 1993 with the idea that examination of natural refrigerants should be done from a long-term viewpoint.

Among natural refrigerants, CO2 was focused on because it has unique properties. Basic studies began in 1995. It was confirmed that a higher COP can be theoretically obtained from CO2 than any other refrigerant when making hot water. The reason is described in Fig. 2. It can be seen from Fig. 2(c) that CO2 does not condense, unlike normal refrigerants, and that its temperature decreases gradually as water is heated. For this reason, irreversible loss is reduced, bringing about a higher COP than Fluorocarbons. Though the two-stage compression system had been invented previously, the use of CO2 enabled us to achieve an almost ideal hot water heating.

Back in those days, R&D of CO2 refrigerants was already underway in Europe, but not in Japan. So a basic experiment loop for a CO2 heat pump was designed, fabricated and installed (Fig. 5) in March 1996. At that time, there was no compressor able to operate on the pressure of CO2. For this reason, a company that was small in size but specialized in high pressure gas processes was found and it made the compressor for the loop despite its misgivings. Using the experiment loop, the feasibility of the CO2 cycle, its control method and heat transfer were investigated. As a result, it became certain that CO2 is a promising refrigerant for hot water supply.

4. Joint development of CO2 heat pump water heater

In March 1998, when it had been found that the CO2 refrigerant could be put into practical use and was a promising refrigerant for hot water supply, a sales representative from TEPCO visited CRIEPI for inquiry into natural refrigerant technologies for use in air conditioning. Introducing that CO2 is a good refrigerant for hot water supply, he understood the excellent properties of CO2 as a refrigerant for heat pump water heater. In this way, making in-house arrangements for the development on both companies was started. However, it is true that only a manufacturer can actually produce a product, so it was necessary to find a manufacturer to be able to participate in our development.

In May of the same year, 1998, an international conference on natural refrigerants was held in Europe. CRIEPI participated in the conference and made a presentation about the results of basic studies of CO2 heat pump. DENSO from Japan also presented the development of a CO2 car air conditioner. While listening to the presentation, it was convinced that DENSO could develop the CO2 heat pump water heater. During the conference, meetings between CRIEPI and DENSO were held intermittently. In July, a representative from TEPCO visited the DENSO and discussed about a joint development. Its first reaction was not so good because DENSO was a car air conditioner maker. During the course of the explanation of the development technology, however, DENSO agreed to the offer. In effect, the joint development project began from October.

During the joint development, a wind tunnel for testing a prototype of CO2 heat pump water heater was installed in CRIEPI as shown in Fig. 6(1999). Using the wind tunnel, a lot of tests on the prototype (Fig. 7) were carried out. Measuring, analyzing and evaluating COP and efficiencies of elements were done. Development issues were abstracted and measures for performance improvement were investigated. Improved components were sent to CRIEPI by DENSO. These components were assembled, tested and evaluated, and then results were returned to DENSO. This cycle was repeated over and over again. Finally it was confirmed that our initial goal for the developed technology could be achieved.

Anyway, after going through many ups and downs, the “Eco Cute” was commercialized for the first time in the world in May 2001. As they say, "third time lucky" applies to CRIEPI. Past experiences of previous two failed attempts at commercialization contributed greatly to the success of this development project.

5. Conclusion

In this paper, mainly our hard-luck story prior to the advent of Eco Cute was introduced. Looking back on the development of Eco Cute, it really got started in a timely fashion with good connections between people, each of whom had their own role to play. In the end a good outcome was achieved through each of us aiming at the same goal. Finally the Eco Cute that was installed in my home was introduced in Fig. 8. Taking responsibility as a developer, it was purchased in 2004 and has been used more than 10 years. In heavy snow of February 2014, it had failed. But after repair it again started producing hot water.

Besides, detailed hydraulic calculation, monitoring system, using the double pump like shown in Figure 1, etc. can be taken into consideration. Hydraulic transmission system aims to improve the flexibility of the adjustment and control, make it better to adapt to changes in system load, reduce the energy consumption of distribution system, and improve the energy efficiency of the system under the premise that the system is stable.

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Reference

[1] http://www.jraia.or.jp/english/excel/shipments_fy_e.xls

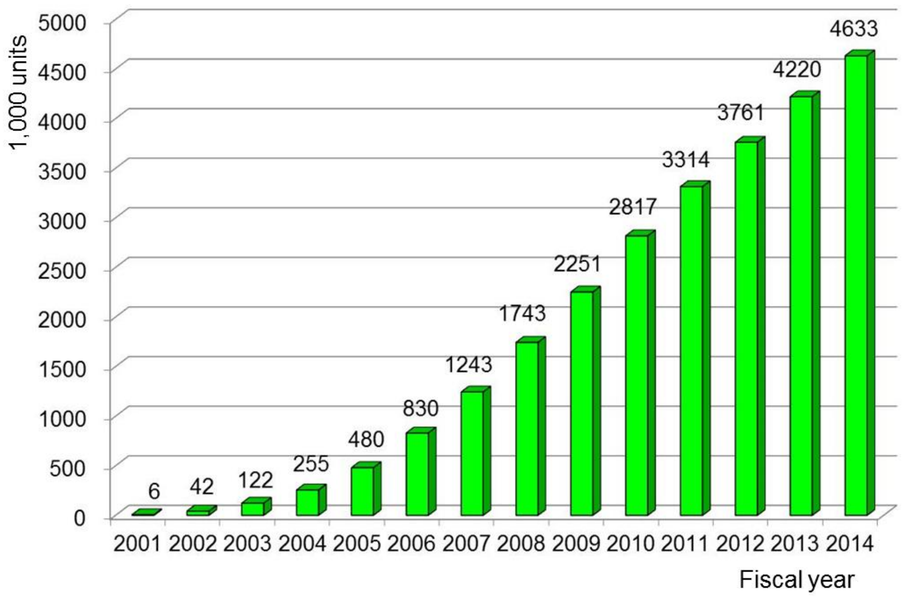


Fig.1 Cumulative shipments of “Eco Cute” CO2 heat pump water heater for residential use in Japan (Made from the statistical data, such as JRAIA[1])

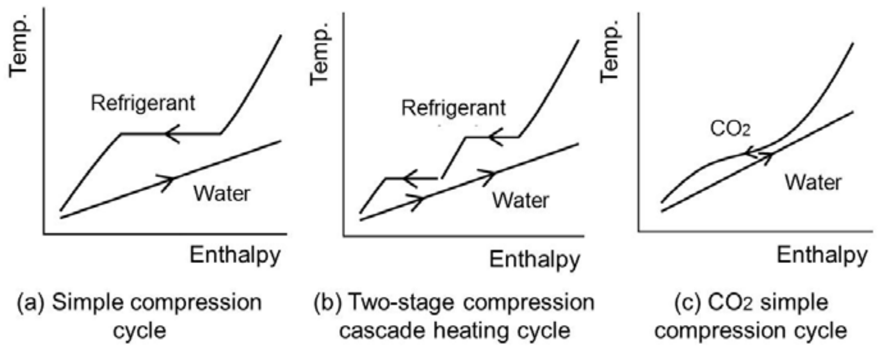
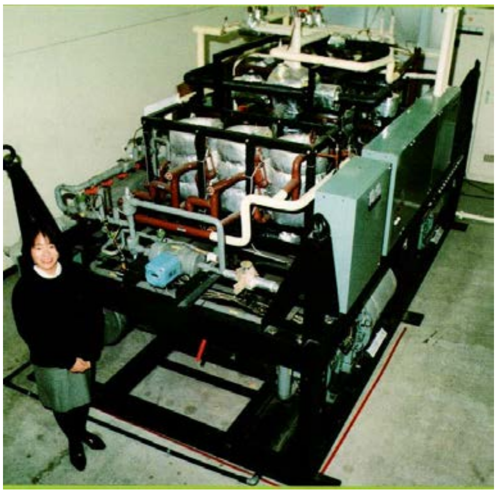
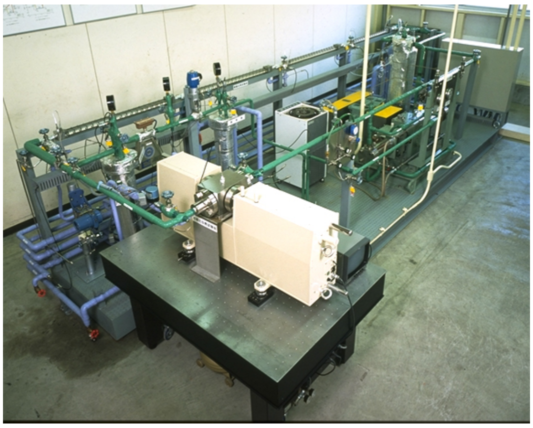


Fig.2 Comparison of heating cycle（Temperature - Enthalpy Diagram）

Heating capacity 4kW, installed in 1987
Fig.3 Experimental apparatus of two-stage compression system

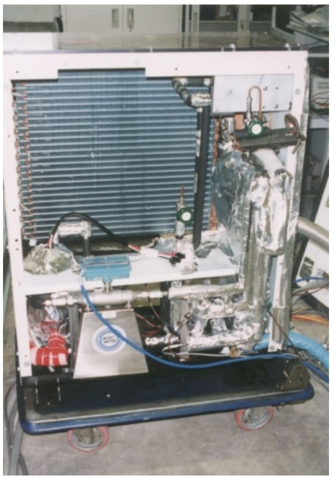


Heating capacity 150kW, installed in 1991
Fig.4 Prototype of two-stage compression system for business use



Heating capacity 4kW, installed in 1996
Fig. 5 Basic experiment loop for CO_2 heat pump

Heating/cooling capacity 5kW, installed in 1999
Fig.6 Test chamber for prototype of CO_2 heat pump water heater



Heating capacity 4kW, installed in 1999
Fig.7 Prototype of CO_2 heat pump water heater for residential use

Heating capacity 6kW, tank capacity 460L, 2004 model
Fig.8 Eco Cute of my home

Asian Heat Pump Thermal Storage Technologies Network

To promote energy savings and combat global warming, there is an urgent need to spread efficient heat pump and thermal storage technologies on the demand side. Countries in Asia, which are enjoying rapid economic growth, should coordinate with one another to spread this technology. Five to ten years from now, Asia will become a global economic powerhouse and heat pump technologies will play a considerable role in all sectors. Asian countries will therefore need to address common issues and problems that have already been faced in Europe and North America. Concerning the building of connections and networks among countries, it is essential to share information on diffusion policies, technology trends, applications, etc., and then to make incremental improvements. Further, situations which can or should be handled through collaboration should be handled flexibly, on a case-by-case basis, with the collaboration of all countries.
In order to encourage the use and development of heat pump and thermal storage technologies in Asian countries we have established AHPNW in 2011.

Participating Countries and Entities

CHINA: China Academy of Building Research (CABR)

INDIA: The Energy and Resources Institute (TERI)

JAPAN: Heat Pump and Thermal Storage Technology Center of Japan (HPTCJ)

KOREA: Korea Testing Laboratory (KTL)

VIETAM: Hanoi University of Science and Technology (HUST)

THAILAND: King Mongkut’s University of Technology Thonburi (KMUTT)

INDONESIA: Heating, Cooling & Thermo Fluids Technology Indonesia (HCTFTI)

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