STRATEGIC PROMOTION OF HEAT PUMP SYSTEM AND ITS ASSIGNMENTS

Katsuhiko NARITA (Dr.)
SHASE Study group of Environment & Energy
(Tokyo, Japan)

ABSTRACT: Trials & efforts to promote Heat Pump Systems, difficult problems to overcome, and what had done and achieved. Current problems to concern, Suggestions for future goal

Key Word: target of markets, successful examples, heat recovery

1 Introduction

The capability of heat pumping by thermodynamic method was, it is said, discussed in the British Society of Natural Science in 1800s. Many have tried to realize the idea, and some successful cases we can notice in the past.
But simple and easy burning skill that mankind had learned since ancient time stood in its way, and some definite conditions such as a sudden jump in price or shortage of fuels during the Wars were essential factors for the use of Heat Pumping technique for a long time.

The situation in Japan was quite the same. Heat Pumping technology had not been noticed in Japan until the Russo-Japanese War (1904~5). Dr. Kaname Otsuka, Prof. of Kyoto University submitted one paper titled ” Suggestion of the diverted use of cooling devices for heating to save fuels ” in 1926.
Among many Japanese challengers enlightened by his suggestion, Mr. Masanosuke Yanagimachi devoted himself mostly to realize Heat Pumping applications. He established The Takasago Heating Company (Later The Takasago Thermal Engineering Co.) and succeeded in the production of the first turbo refrigerator in Japan, and also tried to develop many remarkable heat pump systems with heat storage using the diverted cooling devices. He designed a smaller capacity heat pump than max peak load and extended its operation hours to store heat into a heat storage tank to meet the whole daily heat demand, which resulted in more reasonable initial and running cost of the system. At that time the initial cost of the heat pump was very expensive.

2 GROWTH OF HEAT PUMP SYSTEM WITH HEAT STORAGE

2.1 Social And Economic Back Grounds

The World War Ⅱ suppressed people’s use of air conditioning and heat pump systems in Japan. But in 1960s economic activities in Japan recovered and grew rapidly. Energy demand, especially electric demand not only for industrial but also for people’s use increased suddenly. Japan was short of natural energy resources, so endeavored to get the resources from foreign countries, and all electric power companies invested enormously for developing power generating stations. Fig.1 shows the rapid growth of peak load of electricity in the service area of the Tokyo Electric Power Company (TEPCO) in this period. In 1968 summer peak demand exceeded winter peak because of penetration of cooling, and yearly increase reached 2GW in 1973 .Vigorous industrial activity, on the other hand, produced much

quantity of pollutants and waste heat, and polluted city circumstances causing car fumes, acid rain, and so on, and countermeasures must be quickly introduced in later 1960s.

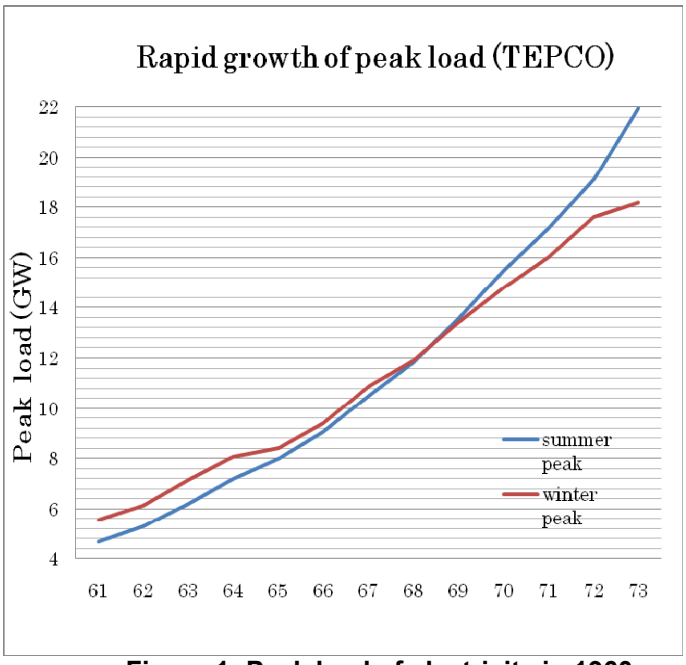


Figure 1: Peak load of electricity in 1960s

Here is a leaflet titled " Recommendation of a new air conditioning system" that TEPCO made in 1960 to endorse " air conditioning system with heat storage " TEPCO aimed to slow down the electric peak load caused by rapid growing air conditioning in every field, but the leaflet showed a traditional combination of a refrigerator and boiler as heat source devices. At this moment TEPCO did not seem to have confidence in a heat pump, and simply wanted to slow down the growth of the peak demand, but it was the beginning for TEPCO to built closer communication with construction companies, building owners, and designing engineers.

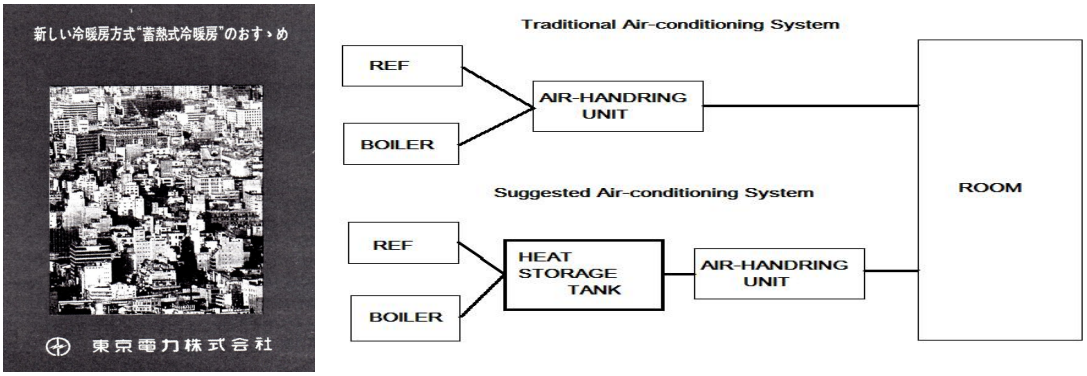


Figure 2: A leaflet titled " Recommendation of a new air-conditioning system "

2.2 The first trial of heat pump systems at Gunma and Chiba branch office

In planning to build Gunma and Chiba branch offices in 1960, TEPCO decided to adopt a heat pump system using well water as heat source, affected by Mr. Yanagimachi achievements.

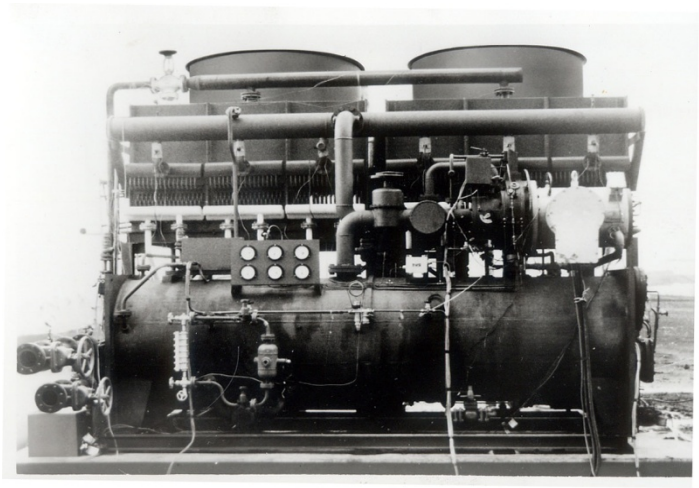


Figure 3: The first model of air source heat pump

There were many unknown and uncertain issues in designing and carrying out the project at that time, and hard and eager efforts through trial and error resulted in more remarkable performance than expected when the branch offices were completed. The system operation was stable with high coefficient of performance.
The remarkable performance achieved in these buildings led me
to the idea of developing a new air-source heat pump. An air source heat pump can be used anywhere without local restriction of well water. There were many difficult problems to be solved such as operation noise in night running time, high pumping head, defrost control etc. TEPCO developed the first model of air source heat pump of 100rf ton employing twin-turbo compressor collaborating with The Ehara manufacturing, and tested the performance with some measuring devices at TEPCO Ota branch office building in 1964. It worked very well as expected but the operation noise during night time was the most difficult problem to be solved because of the building location.

2.3 TEPCO's Decision To Promote Heat Pump Systems With Heat Storage

In May of 1969 TEPCO's administration decided " Recommendation of heat pump systems for air conditioning in the city " to reduce urgent growing of electric peak demand, to level daily and seasonal electric demand, and to contribute to keep healthy city environments. TEPCO took the initiative in adopting heat pump systems in the branch office buildings.

3 STRATEGY AND PROCESS OF POPULARIZATION OF HEAT PUMP IN JAPAN

3.1 The Targets Of Market

Office buildings were the first target, where good operation and maintenance could be expected, and then district heating and cooling projects collaborated with urban developers and local governments, in some cases the project included apartment houses, and finally residential houses which required special careful specifications for the heat pump system.

TEPCO' office buildings more than 300 adopted heat pump systems with measuring devices, and were used especially for demonstration of heat pump systems showing their actual results. Building owners who intended to adopt HP systems were willingly supported by TEPCO in various ways including low charge for storing heat in night time.
The OTSUKA branch office building, which was a TEPCO's model building equipped with a heat recovery heat pump system with heat storage, showed more than 50% reduction of energy consumption compared with that of the traditional buildings. Heat pump systems were improved from air source to heat recovering mode when cooling demand existed in the

building and to providing hot water supply..
Total building designing was also important, such as the use of insulating materials on outer walls and draft depression of the building, solar shade control and resulted in the decrease of heating demand a great deal. Such devices were also introduced as outdoor air control, recovering heat from waste exhaust air and water, controlling of lighting, and remote controlling operation of the heat pump system estimating next day's heat demand and these trial spread to other owner buildings.

In urban redevelopment projects the introduction of district heating and cooling (DHC) system was encouraged by the government to keep healthy city circumstances, then HP systems recovering various waste heat were recommended and constructed by collaborated enterprises of TEPCO. Hikarigaoka project in 1983 was the first example of heat pump DHC system utilizing waste heat from generators in Hikarigaoka incineration plant.

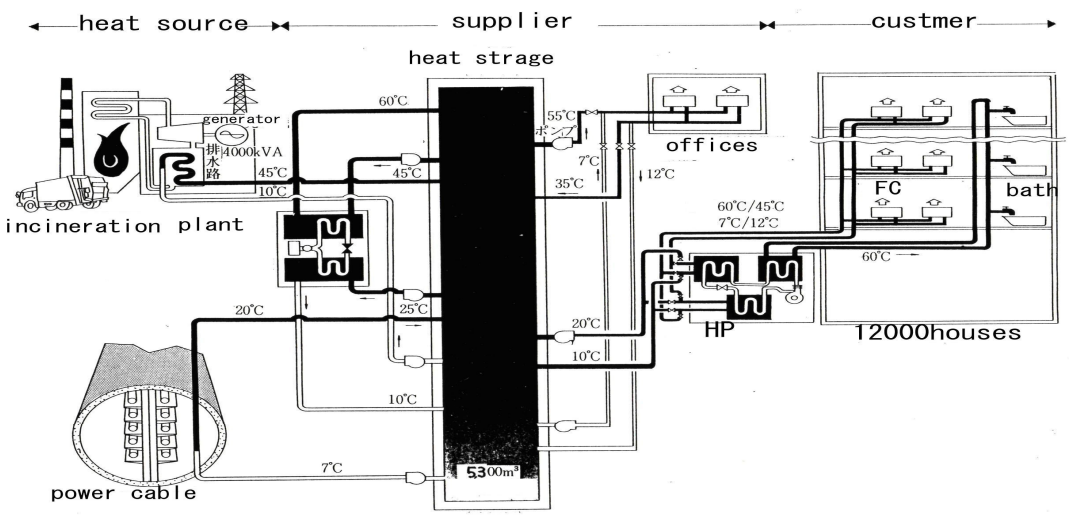


Figure 4: DHC concept of Hikarigaoka project utilizing urban waste heat

Some examples of Heat Pump DHC projects that used various waste heat are as follows

Project name of DHC	Heat source
1984 Ginza area	waste heat from a local transformer station
1987 Sibaura and hibiya	waste heat from a local transformer station
1989 Hakozaki and hitachi	river water and waste heat from the factory
1990 Makuhari, 1994 Korakuen	sewage water
1991 Utsunomiya	ground water

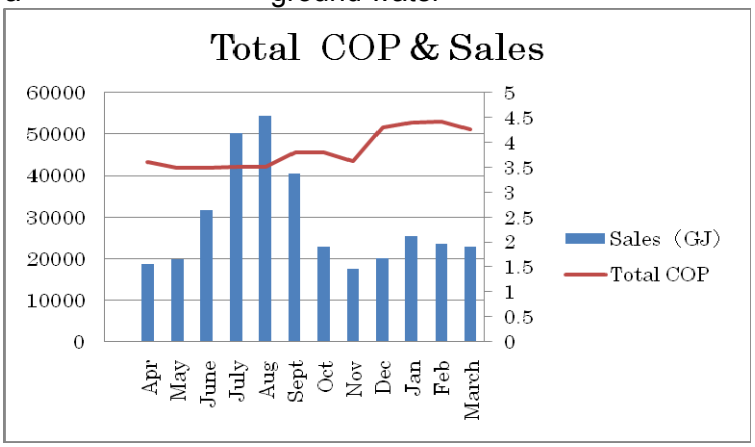


Figure 5: Monthly total COP in MH Plant

Figure5 is an example of monthly total COP at MH DHC plant recovering heat from sewage

water. DHC system has often disadvantage of heat loss and pumping power in distributing process, but the merit of COP improvement attained by recovering waste heat exceeds the disadvantage, and the actual efficiency of primary energy base is estimated to be 1.27, and the volume CO2 ejected / heat demand reduces 40% as compared with that of average building.

$$\text{Total COP} = 4.2Q / (E * 860) \quad (1)$$

Q: Sales heat (Gj), E: Total Energy Consumption in the plant (GWh)

Heat pumps for office buildings have made a great progress in designing and engineering, such as defrost control, regulating refrigerant flow, and the outdoor unit was developed to supply heat for more than two room-units, and then multi-purpose heat pumps that could heat the building by recovering heat of cooling at the same time. Now multi-purpose heat pumps were developed and becoming popular in Japan.

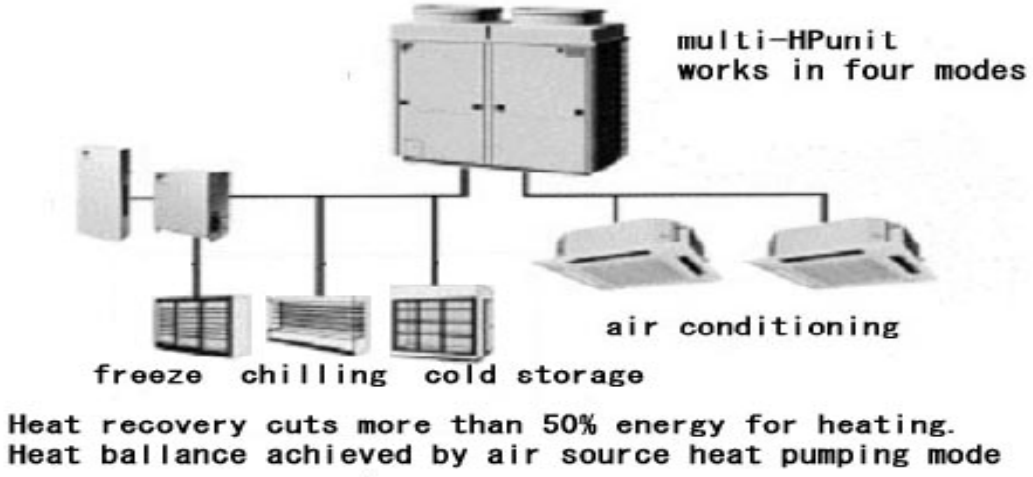
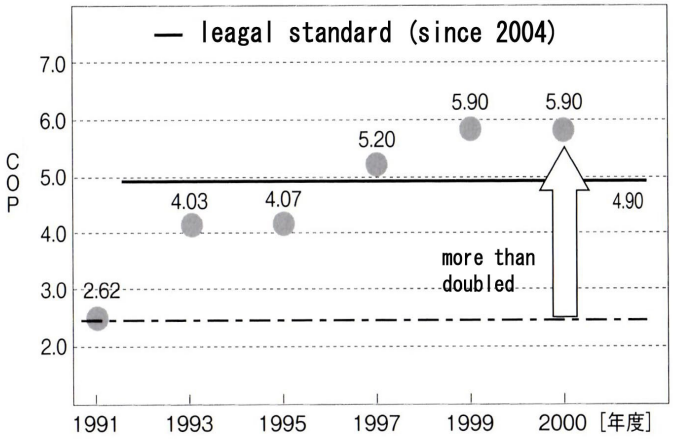


Figure 6: An example of multi-heat pump unit

Another remarkable development of heat pump systems for office buildings is controlling of operation. Heat demands (heating and cooling) of a building vary every moment according to seasonal outdoor conditions and how to use the building, and to attain the maximum seasonal efficiency the controller decides how many units operate for distributing total load to each unit. The seasonal COP of successful examples exceeds 7.0

Heat pumps for residential houses are required severe specification such as quick response, low operation noise, durability, and reasonable initial cost, and installation space for heat pump at the site. They are tough problems to overcome, and final development of separate type heat pumps equipped with a rotary type compressor by an inverter control is now one solution for the requirement at present.



Trend of COP (heating & cooling) Daikin Co

Figure 7: COP of Heat Pump for Residential Use

As for heat pumps for residential house “top runner system “ supported by the government accelerated the performance of heat pumps. All heat pump makers have competed to get top ranking of COP which has been published officially by the authorized facilities.
Heat pumps for residential use are more than 40 million units and yearly sales exceeds often 5 million units in Japan

3.2 Programs To Overcome The Difficulties

Difficult points of the heat pump systems at the early stage
(1) A heat pump was little known and costly
(2) Past common design standards for air conditioning were based on burning devices
(3) Designers were not so familiar with the design standards of heat pumps
(4) And heat pump makers were not confident on heat pumps yet
Activities done to overcome the difficulties
(1) Readjusting of design standard suitable for a heat pump system with heat storage, such as design temperature of media in the air conditioning system, comfortable condition, calculation of heat load,
(2) Collaborated study and developments of heat pumps with manufacturers
(3) Suggestion of designing method for heat pump systems with heat storage
(4) Taking initiative to adopt heat pump systems and collection of their achievements
(5) Establishment of net work of studying and training for related engineers
(6) Public information of actual achievements and their merits
Continuous effort of improvement of the heat pump systems and desirable solution of the problems have been tried until now.

4 MAIN FACTORS THAT HAVE LED THE HEAT PUMP SYSTEMS TO THE SUCCESS

4.1 Weather Condition And Economic Power In Japan

Hot and humid summer and relatively mild winter in Japan is advantageous to an air source heat pump, and industries have enough economic power to develop heat pumps and have been urged to develop heat pumps by the public opinion of environmental protection.

4.2 Joint Activities of 9 Electric Utilities in Japan

9 electric utilities (later 10 utilities including OKINAWA Electric Company) had common problems of rapid growth of peak load in summer caused by air conditioning in 1960s and heat

pump systems with heat storage seemed to be one of the effective means to slow down the rapid growth of electric demand. They promoted the development of heat pump systems with heat storage working together.

4.3 Establishment Of IEA (1974) Soon After Oil Crisis (1973)

IEA activities of developing and promoting heat pumps encouraged people concerned of heat pumps.
IEA report " The common strategy of member countries(1978)", " The technical review of heat pump(1980) " and " The First IEA Heat Pump Conference (Graz, At, 1984) " encouraged those who had been working to develop heat pump systems. Some groups started to study heat pump systems using the Conference Proceedings as a text.
Going with the current, Japanese government set up national project " Sun Shine program(1974) ", " Super Heat Pump (1978) " and enacted " The law of rational use of energy (1979)". In 1986 Heat Pump Technology Center of Japan, in 1978 Energy Conservation Center established. Announcement of " Top runner and labeling systems " started in 1999 for promotion of rational use of energy.

5 CURRENT ASSIGNMENTS AND THE RECOMMENDATION

5.1 Understanding Of The Environment In The Viewpoint Of Heat

The following understanding should be accepted clearly and widely
(1) Energy consumption inevitably produces waste heat. There are various low efficient apparatus used in daily life. For example, the efficiency (chemical energy to heat) of a gas heater and stove is around 60~80% and the loss of 40~20% changes to waste heat. Increase of energy consumption means increase of waste heat as well.
(2) Global energy resources and capacity to accept waste are limited.
The fossil fuels are precious products of very old history of the globe, and said to be short within dozens of years, if the present pace of consumption continues.
(3) And the natural environment is full of heat from the view point of heat engineering.
Even the air at 0 degree C has heat itself compared with that at -10 degree C.
(4) A heat pump functions by recovering heat of cooling, in other words, a heat pump is not only a device of heating, but a device of cooling at the same time. If heating demand is covered by the heat recovered from cooling demand, the efficiency of the heat pump system shows doubled value. Imbalance between cooling and heating demand can be adjusted by heat storage systems.
(5) A heat pump can supply much more quantity of heat than input energy by recovering heat from environment and waste heat.

Heat pumps reduce pollution of environment using energy effectively, and restrain the growth of energy consumption. Therefore heat pumps should take the priority over other heating methods in daily heat demand.

5.2 Assignments

It seems that the progress of this half century's heat pump system shows the change of heat source firstly from well water to air, and secondly to cooling load in the same building, and waste heat ejected to the circumstances.
Current problems to be concerned
(1) Development of new suitable refrigerants, and proper installation and maintenance technique that diminishes the leakage. Even though any remarkable refrigerant is developed heat pump cycle must be kept with no leakage. Life-cycle management of refrigerants (establishment of recycle and reuse system of refrigerants.) should be introduced.

(3) The growth of hot water use in residential field is now prominent in Japan, and the many trials of heat recovery from the used hot water should be recommended.
(4) Various buildings in urban area are connected each other with infrastructure and consume a large quantity of energy for various purposes rejecting a lot of waste heat. Trials to versatile reuse of waste heat among the buildings in the targeted area are recommended.
(5) For that purpose, the research of various heat demands and ejected various heat in various buildings in local area should be promoted. .

Cooling load, if rejected, becomes waste heat that bothers environment, if recovered, it changes a precious heat source.

The goal could be the combined heat pump system which recovers local waste heat with a large heat storage system. The system is controlled to balance total local heating and cooling demand by recovering various heat sources automatically. This system requires the operation of heat exchange beyond the area only when the heat balance is not kept within the group of local buildings in the area.

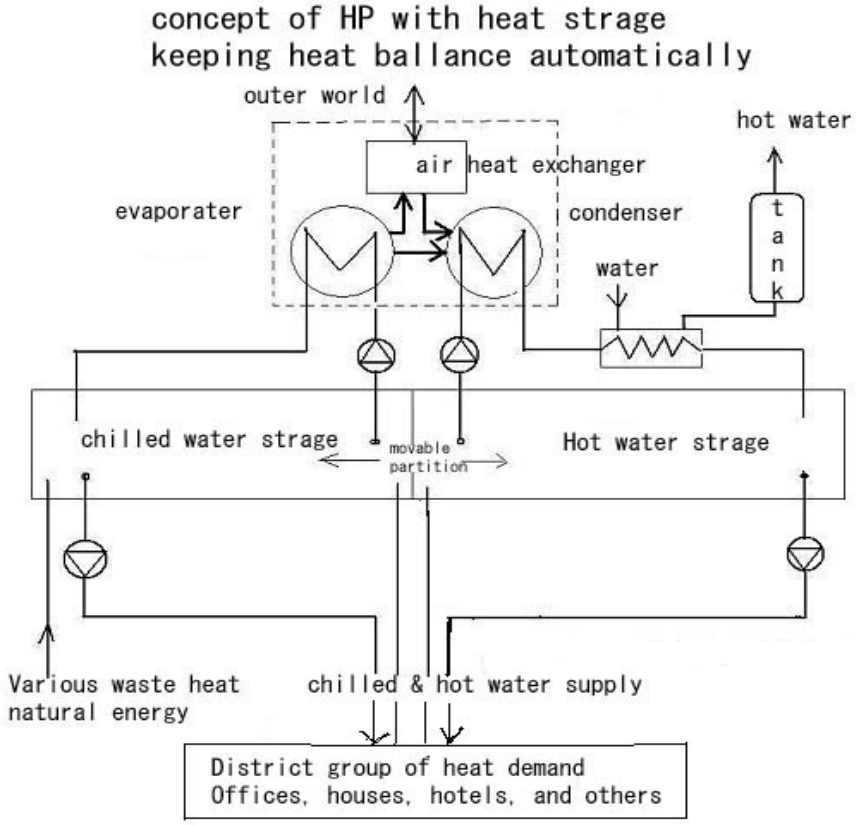


Figure 8: The concept of total heat recovery system with heat pumps

Underground electric transmission lines, sewerage systems and rivers in the city are main flow lines of waste heat rejected from various facilities in urban area, and could be good heat sources for heat pump systems. Imbalance of local heat recovery system (heating and cooling demand) could be compensated by the waste heat through these lines. Establishment of the net work of heat source lines in urban area where each facility recovers and rejects heat according to its need could promote the use of heat pumps.

5.3 Recommendations

To get the backing of public opinion,

(1) Improvement of durability and longer life guarantee of heat pumps especially for residential use. One year's guarantee at present is too short, the guarantee period should be extended to 5~8 years with cooperation heat pump makers, distributors and service shops.
(2) Announcement and publishing of possible role of heat pump systems and achievements, and recommendation of taking the initiative to accept heat pump systems.
(3) Campaign " heat supply (heating, hot water, drying) by heat recovery of cooling load "

" Cooling load is a precious heat source for heat supply ! "

Engineers concerned are encouraged to investigate
(1) Research and analysis of various heat demands in the targeted buildings in the area.
(2) Total local heat recovery design by collaborating neighboring building owners.
(3) Managing heat recovery systems, grasping actual performances and assessment. .
And transferring of the technology and experiences of heat pump systems to developing countries is the important mission as well.

6 CONCLUSION

(1) Make maximum efforts to realize the total system of advanced local heat utilization with urban planners and local inhabitants in the target area.
(2) Establish the local heat recovering systems, and widen a great role of heat pumps in the global environments and limited natural resources problems.
(3) Transfer the technology and experiences of heat pump systems in Japan.

7 References

IEA 1978 " Common strategies of IEA member countries "

IEA1980 " Heat pump systems A technology Review "

IEA1984 " Proceedings of IEA Heat Pump Conference in Graz "
(Japanese)

Unused energy study group 1983. " Final report on unused energy "

The Agency of Natural Resources and Energy 2005 " Recommendation for local energy use"

Total research society of resources and energy 2007.6 " The direction of energy conservation from now "

The Heat Pump Technology Center of Japan 2009 " White paper on Heat Pumps "

Katsuhiko Narita 2008 " Heat Pump Systems with heat storage recovered cooling demand "

Katsuhiko Narita 2009 " TEPCO and Story of Heat Pumps "