PROGRESS OF COMPRESSION TYPE HEAT PUMP SYSTEM AS THE TYPICAL ADVANCED CASE OF "GREEN INNOVATION" AND THE PROMOTION OF ENERGY SAVING BY REALIZING THE ADVANCED HEAT PUMP AIR CONDITIONING SYSTEM

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Abstract: The commercialization of advanced heat pump system developed by the Japanese national project of "Super Heat Pump Energy Accumulation Systems" has been reviewed from the viewpoints of overcoming the death valley of research and development. The coexistence of higher performance and reasonable cost would be the key factor for realizing the world-wide spread commercialization.
The performance of compression type heat pump system has been developed for doubling the value of COP in these 15 years. Then, the heating and supplying hot water by use of electricity generation and heat pump system would have higher performance over 2 times compared to the case of burning the fossil fuels directly. Therefore, as the typical example of green innovation, the heating by burning the fossil fuels would be replaced by the combination of the heat pump system and the electricity generation. Furthermore, by utilizing the advanced heat pump system, the large amount of energy saving would be possible for the case of large scale laboratory. For promoting the energy saving over the world, the international standardization would be important for smaller amount of ventilation.

Key Words: advanced compression type heat pump system, Super Heat Pump, death valley, Green Innovation, energy saving

1 INTRODUCTION---RESEARCH AND DEVELOPMENT OF "SUPER HEAT PUMP"---

The compression-type heat pump system has been researched intensively to have higher performance and to be widely applicable to the various climate conditions over the world for these 30 years. One typical example is the research and development of "Super Heat Pump Energy Accumulation System" conducted by Japanese National Project of "New Sunshine Project". The history of the research and development is shown in Fig. 1. The ordinate is the number of commercialized products or the public interests and the abscissa is the year. The first 10 years was the period of national research and development project, where the advanced heat pump system had been realized to have the higher value 2 times of the conventional COP for the building condition. The latter 10 or 15 years was the struggle period to realize the coexistence of the reasonable cost and the higher performance for obtaining the successful commercialization, where the development activity had not been referred largely by the society and nearly no scientific paper has been published. This latter period of the research and development has been called as the "Death Valley" or the "Period of Nightmare" of the research and development of technologies. Many developed technologies have the similar longer period of development called Death Valley for realizing the commercialization after the success of the fundamental research. After overcoming the Death Valley, the developed Super Heat Pumps have been commercialized and been widely spread all over the world.
The technological characteristics of Super Heat Pump would be as follows. 1) Improving the compressor efficiency by decreasing the leakage gap. 2) Improving the heat exchanger by

increasing the heat transfer coefficients. 3) Improving the performance by realizing the idealized thermal cycle similar with the Lorentz cycle.

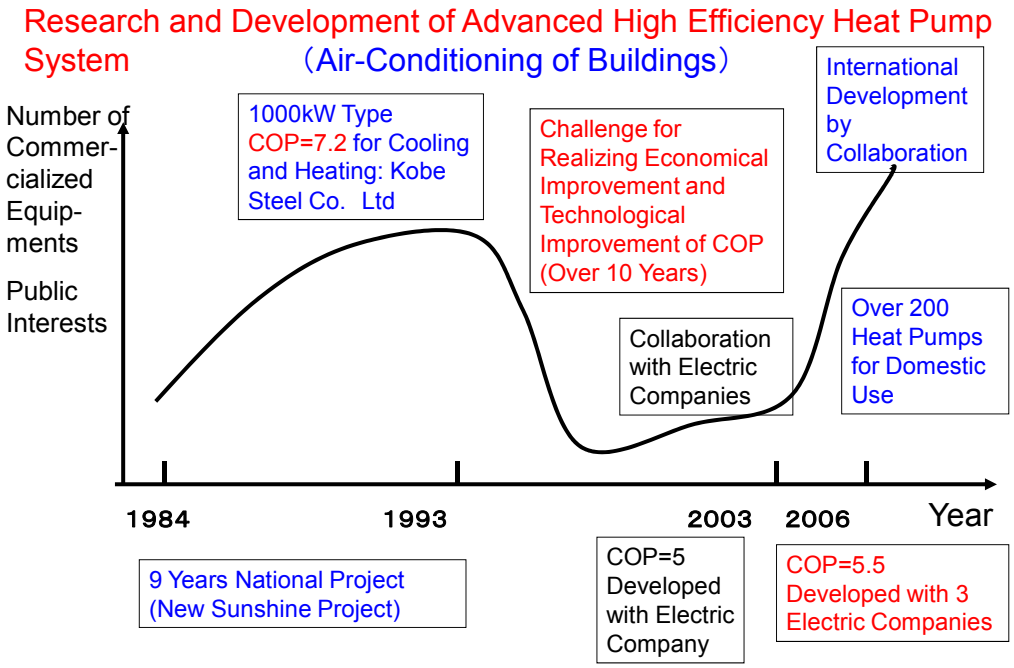


Figure 1: Research and Development of "Super Heat Pump" System

2 IMPORTANCE OF "SOCIAL TECHNOLOGY" FOR OVERCOMING DEATH VALLEY

As for the Death Valley, many fundamental researches developed in the "New Sunshine Project" have the similar history and therefore many new challenges remain still in the Death Valley. However, there should be the methods of overcoming the Death Valley for successful commercialization. We named the important and widely applicable methods for overcoming the Death Valley as the "Social Technologies", where the developed technologies have been evolved and reinforced by the other technologies to be applicable in the society. The important viewpoint of research and development should be the establishment of "Social Technologies" for the commercialization and the concept and the systematization of "Social Technologies" should be proposed and brought up widely to the world society.

"Social Technologies" should have the following characteristics as shown in Fig.2. (1) Key application area should be clear. (2) Economical feasibility would be necessary. (3) Reliability and long lifespan would be necessary. (4) Higher performance and discrimination from previous products would be necessary. (5) Social acceptance by public demonstration would be necessary. (6) Establishment of social necessary conditions, such as environmental acceptance, traceable condition, strategy of standardization and social risk evaluation would be important.

In case of Super Heat Pump system, coexistence of higher performance and economical feasibility would be the most important key factor and over ten years would be necessary for satisfying this condition. The collaboration among the manufacturing company and electric companies would be very helpful for overcoming this condition.

Another characteristic for overcoming the Death Valley would be the existence of key research person who has been continuing to research from the fundamental stage till the development stage for commercialization over 20 years.

The economical feasibility could be calculated from the beginning of research period, and the idea that could not contribute to the economical feasibility should be dropped its priority level beforehand. It would become much more important that what kind of new concept could you

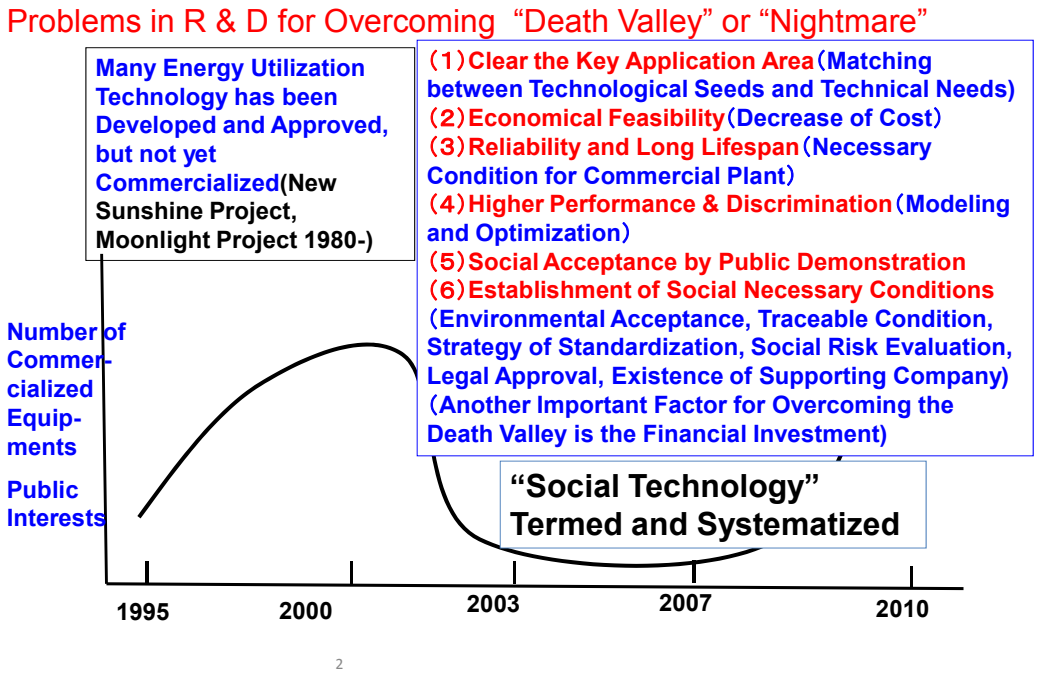


Figure 2: Systematic Approach for Overcoming the Death Valley of R&D -Social Technology-

able to offer, or what kind of product could you realize compared to the expression of what kind of new technological seeds were able to be done. The technological seeds side and the user side might be able to be closely related as much as early. To make the discrimination, to prove the priority by calculating efficiency and to demonstrate in the society would become very important. In addition, to overcome the Death Valley as early as possible would be very important and would be realized by discussing the social necessary conditions with many related key persons. However, when the technology is developed, neither such an idea nor the methods of overcoming the Death Valley would have comparatively written in the scientific papers and would become some kind of know-how.

Then, National Institute of Advanced Industrial Science and Technology (AIST) made the new scientific journal named "SYNTHESIOLOGY" four years ago. The main topics of this new journal would be the publication of methods of overcoming the Death Valley for commercialization and the methods of synthesizing and building up the new product. The growing technology would be reinforced by other technologies or adapted by using a certain technology. The integration of technologies, which would be called synthesis, would be important and would be understood as a common methodology to everyone. Moreover, by making an English version the discussion of the methods of Death Valley and of synthesizing the new products could be spread all over the world.

By the way, the overcome of the Death Valley of the research and development would be the most important for the researchers, but for the business headquarters of the company the overcome of the Death Valley would be only the necessary process. For the business headquarters, the period of doing a big investment and the upbringing to a large-scale commodity would be much more important than the Death Valley, since the total necessary budget would be much larger for realizing the large-scale commodity.

An inkjet printer and the digital camera would certainly take 20 years or more for realizing commercialization after the first patent has been invented. The first patent would be invalidated in the stage of Death Valley since the first patent would be invalidated in 15 years. Important patents that would demonstrate much strength when commercializing it on the other hand would have come out around in the period of Death Valley. Afterwards, important patents would be invented in the stage of upgrading the technology and under the discussion among the interactive serious researchers in various fields, which would be much different from the fundamental stage of research carried out independently in the laboratory.

3 AMOUNT OF ENERGY CONSUMPTION FROM THE VIEWPOINTS OF DAILY LIFE

3.1 Energy quantity consumed per person

There would be a little people who could actually feel how much energy has been actually used by ourselves, even if "Energy has been consumed too much" have been frequently said. Nevertheless, the energy problems would be thought as that a lot of people have much concern.
When I use and calculate the data in 1993, the Japanese is always using the energy of 5kW per person on the average. In case of considering only the business room, only the lighting and the air conditioner are used and the electric power consumption would be several ten W per person in the business room. However, at the same time, many items should be added because the factory also is operating and Shinkansen and the car are moving when they could be converted into the average of one person. When families are four people and the energy cost for one person would be about 55,000 yen, the energy cost would be equivalent to 220,000 yen for a family as the electricity bill of one month. However, it can be thought that 10 percent of the entire energy is consumed in the house because it is about 20,000 yen a month for an actual home, and 90 percent of the remainder is used in other places of the society. By the way, this value of 5kW a person is the half of the value for the United States, and nearly the same with the value for Germany and France, and are about three times compared with the values for the global average.
The average energy usage for United States would be large because there are a lot of private cars that drive the long distance and use a large amount of energy. The energy of gasoline and the diesel light oil for the private cars would exceed 400W and the energy to manufacture the raw material and to construct the automobiles would be 90W. Then, the energy used for the private cars would become 490W and would be about 10% of total energy consumption of each people 5kW from the viewpoints of LCA (Life Cycle Assessment). The energy used to make the buildings would be about 300W and the energy necessary to use the building would be 160W and the energy discharged from the power plants for the amount of electricity necessary for the building use would be about 160W, and then the energy for the buildings would be 620W from LCA analysis. This amount would be the 10% or more of the total energy usage.

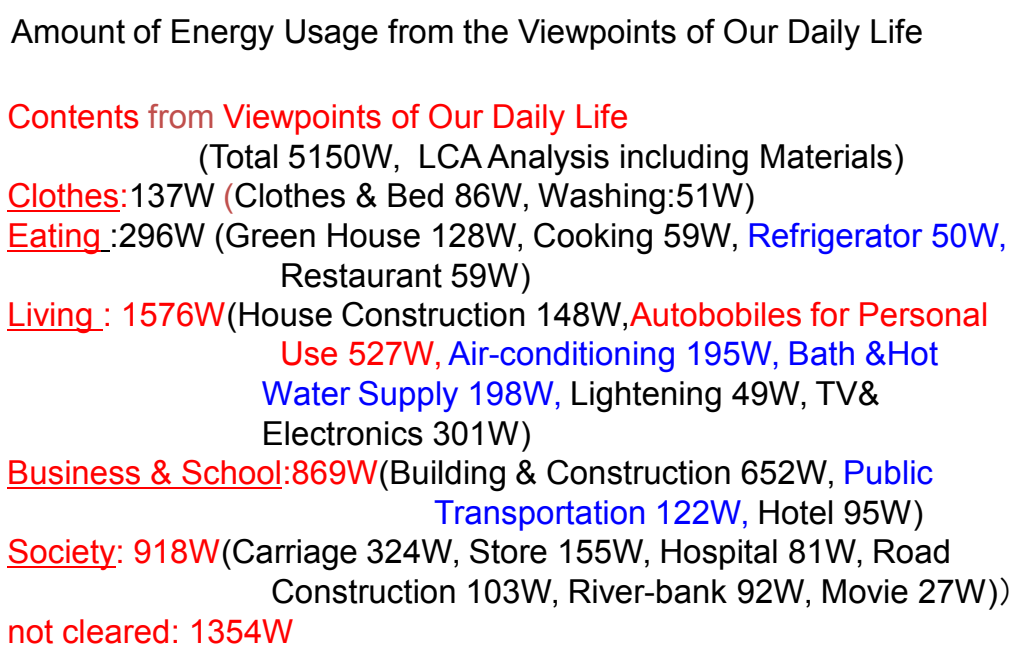


Figure 3: Amount of Energy Usage from the Viewpoints of Our Daily Life

For realizing the future conditions that the energy usage should be decreased by half or 30% in 2050, we could not build and destroyed the buildings frequently as seen in the city and we should continue the maintenance the buildings as long as possible.

3.2 Amount of energy usage from the viewpoints of our daily life

As shown in Figure 3, the energy used for clothing would be about 2% of the whole and they include energy for making the clothes and for wash. As much as 5% is not used for eating though the energy used for the greenhouse, the cooking, the refrigerator, the food service industry would be included. However, 30 percent would be used in the living categories. About 10 percent of the total amount would be used by the private cars. And the thermal energy used at home, such as the air conditioning, supplying hot water and the refrigerator would be accumulated to about 10 percent. The consumer electronics would be increased recently till 10 percent.
On the other hand, no matter how it would be turned off in the company at lunchtime, the energy saved by the lighting would not become the significant energy conservation in many companies where many of employees have been commuting with the private cars because the energy used for the lighting would be one digit fewer than the energy for the private cars. Besides, the energy usage in work and the school would be 20 percent or less and the building would be the half of them. The energy usage for the society and service would be the same levels. The energy usage for home delivery service, the department store and the hospital would not the significant ones.
Thus, the amount of energy usage would be quantitatively estimated in many categories and the effect of energy saving would become more clear for each action of energy conservation.

3.3 Energy consumption from the economical viewpoint

The aspect of the cost would be also the essential matter. For instance, when the private car of the fuel efficiency of ten km/l runs ten km, it costs about 100 yen for the one litter of gasoline. It costs 100 yen in case of air-conditioning all night with the air conditioner in summer. As for taking bath for four family members, the city gas cost and the water cost would be about 100 yen. When kerosene is used in heating all night in winter, it costs 100 yen.
By the way, milk is about 200 yen for a litter in the convenience store of Japan and the kerosene of one litter would be about 70 yen. Furthermore, since the PET bottle of 500cc natural water would be 150 yen, the natural water would be 300 yen for one litter. The kerosene which would be produced during hundred million years in the earth would be a little dissatisfied only with the price of 1/4 of natural water. It might be not so anxious though it would become a fuss if the price of gasoline would come to go up for about 200 yen but the price of the gasoline would be still cheaper than milk.
We could understand that our society would be constructed based on the considerably cheap cost of energy. Therefore, a big influence would be occurred when energy prices rise by any chance.
Recoverable reserves of oil at present would be one trillion barrels and it would be equivalent to one cup of inverse mountain of Mt. Fuji which would be like a cup called an “ochoko” as seen from Tokyo. The oilfields have been newly found continuously so far, but the newly oilfields would become smaller areas and the possible period of oil usage would become saturated and start to decrease. Actually we would able to use at the present rate in another 40 years because the oil of about 27 billion barrels a year (about 3.7 billion tons) would be mined now.
Certainly, the development of environment-friendly new energy has been developed strongly and the ethanol could be made from the biomass energy. However, the cost would be the essential problem. Technological development would be sure to be accelerated much more if the ethanol made from the biomass energy could be sold nor for the same price as kerosene which would be 70 yen but for the price of natural water which would be 300 yen for a litter.

However, the price that could be sold would be low no matter how environment-friendly energy would be developed under the present situation, and it is serious to decrease the economical payback period.
As for the economical viewpoints, the necessary payback years of the initial investment would be very important. For instance, the payback period of domestic photovoltaic generation plants would be about 20 years. However, the energy conservation technologies which have the payback period of less than 3 or 4 years have been positively utilized by many factories so far. It would be important that the energy conservation technologies which have the payback period of less than 10 years should be promoted to be widely utilized in the society and in the factories.

4 ADVANCEMENT OF COMPRESSION TYPE HEAT PUMP SYSTEM AS THE TYPICAL ADVANCED CASE OF A "GREEN INNOVATION"

The compression type heat pump would be the leading example of "Green Innovation", since the performance of compression type heat pump would become double in these 15 years as shown in Figure 4. The estimated COP of the advanced hot water supply systems in ten years would be also plotted in the figure as the result of the established JSME technology roadmap. It would be one of the technologies that Japan has developed in advance of the world, though a green innovation is an important concept when pondering the problem of the environment now. The performance index named COP (coefficients of performance) has been increased from 3 and reached to 6. The heat pump system would be the renewable energy where the five times of heat would be transferred from the environment to the heat pump system in the heating condition. Twice or more amount of thermal energy would be useful for the heating or the hot water supply by use of the advanced compression type heat pump system compared with the case by use of the direct combustion of fossil fuel, since it becomes 2.4= 6×0.4 if the power generation efficiency 40% is multiplied by the COP value of 6. The fact should be one kind of green innovation, that the usage of advanced heat pump system would be much more excellent for the energy saving compared with the case of using the direct combustion of fossil fuel. This innovation also means that the fossil fuel should be used to generate electricity and the generated electricity should be used in the advanced heat pump system for generating heat and for supplying hot water.

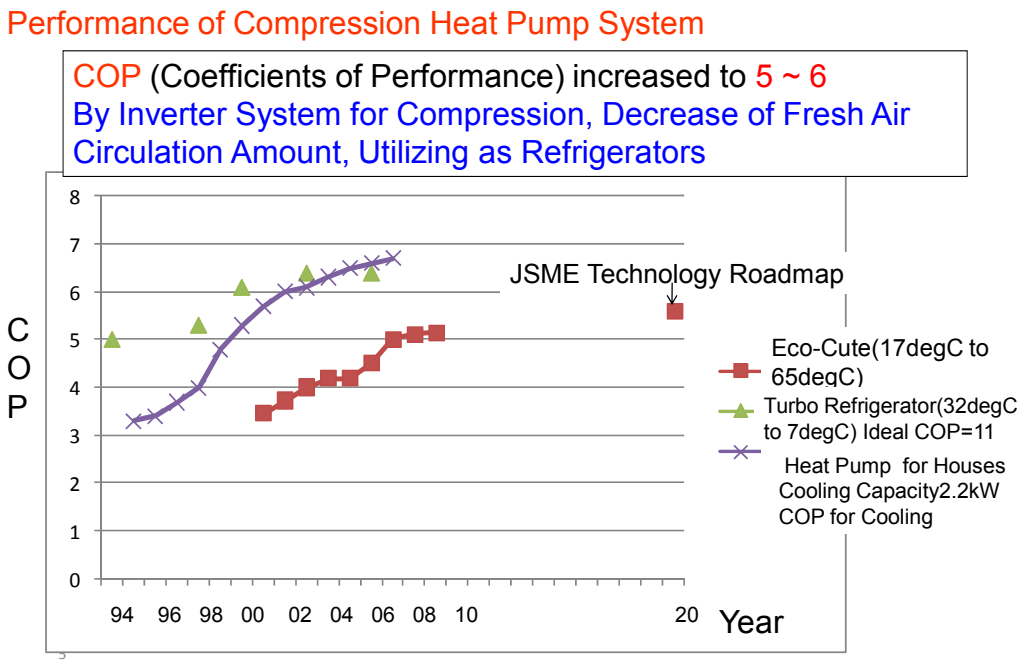


Figure 4: Innovation of Energy Conservation by Advanced Heat Pump System

Moreover, the performance of the heat pumps available in Japan has become one example of an advanced technology of Japan because it is about 50% higher than the one of the United States and Europe according to the 4th assessment report of IPCC.
As for the effect of this innovative energy saving by the advanced compression type heat pump system, the effect of utilization of advanced heat pumps for houses and for buildings would be estimated separately and accumulated as follows.
If the usage for the heating and the hot water supply in houses and in the buildings would be replaced by the advanced heat pump system from the conventional burning system of the fossil fuel, the decrease of the energy consumption would be possible. For the case of houses, the 56% of the total energy consumption would be the heating and the supplying hot water and the replacement by the advanced heat pump system would become the decrease of the energy consumption of $20x10^{13}$kcal. For the case of buildings, the 42% of the total energy usage would be the heating and the supplying hot water and the replacement of the direct burning system by the advanced heat pump system would produce the decrease of the energy consumption of $13x10^{13}$kcal. The total decrease of the energy consumption would be $33x10^{13}$kcal and this amount of decrease would be about 6% of the total energy consumption of Japan.

5 ENERGY SAVING BY ADVANCED HEAT PUMP FOR THE CASE OF LARGE SCALE RESEARCH LABORATORY

In our laboratory of AIST, the target for the reduction of energy usage by 15% in these five years had been set up 7 years ago, and the decrease of about 15% has been actually realized. AIST is one of the largest national laboratories in Japan and the total number of researchers, the technical staffs and visiting researchers would be about 7,000 constantly. The total cost for the energy including electricity and city gas would be the order of 4.5 billion yen for a year, and then it would become the retrenchment in expenses of 700 million yen for the reduction of 15%.
Various methods of energy conservation would be examined and modified to the adequate way. For instance, the total amount of ventilation should be decreased to the smaller value when there was no person in the clean room. For the most cases, 10 times per hour would be used for the ventilation frequency, which would mean that the total volume of air would be 10 times compared with the volume of the room per hour.
The large quantity of energy would be necessary for the air conditioning and for the large amount of ventilation in the clean room, where the large amount of cooled and dehumidified air would be generated and flown through the clean room and been blown out to the environment. Therefore, to decrease the amount of ventilation air to about 50% would be essential and key factor for the improvement of energy conservation.
Furthermore, since the improvement of compression type heat pump system would be remarkable, the absorption type heat pump systems would be replaced by the advanced compression type heat pump systems.
As a result, judging from the economical viewpoint of payback period of the initial investment, the initial investment could be paid back in about 5 year, that would be the conservation of energy of 300 million yen for one year and that would mean the total investment amount of 1.5 billion yen for one year. Promoting the conservation of energy would have become an stage done by making the investment for the better energy saving not by our spirit of energy conservation or our attitude of energy conservation.

6 METHODS OF PROPAGANDA FOR ADVANCED HEAT PUMPS IN THE WORLD—NEEDS VARY FROM COUNTRY TO COUNTRY---

Since the advanced compression type heat pump systems would become one of the most effective energy conservation equipments available all over the world, they should be

promoted to spread all over the world from the viewpoints of energy conservation. However, when we have made the propaganda for these heat pumps in many countries, these energy saving equipments have not been welcomed in several countries. In the developing countries it has been often said that to save energy should be done in the advanced developed countries and that to use more energy should be their exclusive privilege. But, when we explain the advantage of utilizing the advanced heat pumps to decrease the shortening of electricity to the half, these advanced heat pump systems would be welcomed in the countries where the electricity power failure has been occurred frequently.
Also in the developed countries they have not been welcomed only from the energy conservation viewpoints. Many countries wanted their own energy policies and the usage of advanced heat pumps should contribute the promotion of their energy policies. For example, in some countries where the economy and energy policy have been suffered the drastic change of oil price, the heating and hot water supply by use of advanced electricity driven heat pumps would be welcomed since the energy policy would not be influenced largely by the change of the oil price due to the nearly constant electricity price. Actually the price of oil has gone up and fallen for three years of 2008-2010 between 43$/Barrel and 135$/Barrel and the price of electricity would be nearly constant for many countries. Then, the heating and hot water supply by use of the burning of oil should be replaced by the advanced electricity driven heat pump system to change the society and the energy system not influenced by the change of oil price and not sensitive for the oil price.
Furthermore, there would be another excellent motivation method of promoting the spread of advanced heat pump systems. That would be one kind of the green investment scheme and as the results of emission trading the direct burning system of fossil fuels in some countries such as Latvia, Lithuania would be replaced by the advanced electricity driven heat pump system under the proposal of Japanese companies.
In the case of China, the usage of heat pumps would be strongly promoted since the air pollution of the large cities of China would have been serious due to the emission of large amount of polluted burned gas of fossil fuels. Therefore, the heat pump systems which utilized the underground heat source have been widely utilized. If the performance of the heat pump could be raised, the total amount of thermal conservation would become about the half of the total energy usage for the heating and supplying hot water.

7 FURTHER TARGETS OF ADVANCED HEAT PUMP SYSTEMS

7.1 Necessity of International Standardization

There would be two important topics to be considered carefully for the advanced heat pump systems. The first one would be the international standardization of the performance of the heat pump systems, which should be measured on the same temperature conditions such as the ambient temperature for the heating and the cooling conditions internationally. The necessary temperature and the estimated ambient temperature should depend on the climate of the countries, but to compare the performance of the individual mechanical systems could be only conducted by the same temperature conditions. The lack of these measures would become some barrier for the worldwide spread of heat pump systems. Every heat pump system should have the two values of performance depending on the temperature of the country and on the international standard.
The second one would be the international standardization of the energy systems, such as the clean rooms and factory buildings. The amount of ventilation frequency should be minimized from the viewpoints of energy conservation especially in the case of small number of people worked inside of the clean room and in the case of the system which would not emit any dangerous gases. By checking the concentration of carbon dioxide and any dangerous gases, the amount of ventilation should be minimized and decided by the international standardization. They should be the balance between the energy conservation and the safety standard. Especially, they should be reviewed and revised from the viewpoints

of energy conservation. The total amount of energy conservation by reducing the ventilation frequency would have the possibility of 10% of the total energy usage for the large scale laboratory like AIST, since the energy for the clean room would be the order of 30% constantly during the year.

7.2 Realization of Industrial Applications of Compression Type Heat pump Systems

To promote the smart grid of energy systems especially for averaging the supply and the demand including the solar cell and wind power generation, the demand response for decreasing the difference between the power generation and the electricity usage would be essential and the adequate methods of demand response should be seriously requested. One of the key methods would be the usage of compression type heat pump system for generating the cool and hot water to produce the adequate temperature and humidity of air-conditioning of factories and clean rooms. The systematic analysis and the optimization should be conducted to promote the smart grid systems.
For realizing the industrial applications of compression type heat pump system, several application areas would be challenged. The first one would be the heating demand of small temperature difference which would produce the higher performance of COP. They would be the vapor re-compression process in the beer production process, heating and processing for the food production and the high temperature vapor production not only for the hot water supply but also for the sterilization. The second application would be the usage of the inverse heat pump cycle for generating the electric power from the waste heat. The third application fields would be the agriculture fields and they would be the heating and cooling for the greenhouses. Some applications have been realized for the production of fruits and flowers. As for the case of producing the fruits of mangoes, the higher temperature conditions would be realized with the higher performance by the compression heat pumps.

8 CONCLUSIONS

The progress of the performance of the compression type heat pump as the typical advanced case of “Green Innovation” and the promotion of the energy conservation by utilizing the advanced heat pump systems were explained in details and the following conclusions were obtained.

(1) Over ten years of research and development would be necessary for establishing the advanced and commercialized energy equipments after realizing the technological seeds.
(2) To overcome the Death Valley of research and development, several conditions such as the economical feasibility, key application area and discrimination from the previous products, which would be called “Social Technologies” would be essential and necessary.
(3) Quantitative discussion of energy consumption based on the daily life analysis would be useful for promoting the energy saving. For promoting energy conservation, the economical payback years would become key factor.
(4) Advanced heat pump systems with COP of 5~6 has been the typical advanced case of a “Green Innovation” for replacing combustion process and has been utilized rapidly. As for the case of Japan, utilizing advanced heat pump systems by replacing combustion process saves 6% of the total energy usage.
(5) Energy saving by advanced heat pump would bring the retrenchment in expenses for the amount of the reduction of energy usage. The initial investment of the energy conservation equipments could be paid back in about 5 years.
(6) Methods of the propaganda for promoting advanced heat pumps over the world should depend on the situation of each country. They would not only the viewpoints of energy conservation, but also the decreasing the shortenings of the electricity power failure, the establishment of the society not influenced by the change of the oil price.
(7) International standardization for the conditions measuring the performance of heat pump and the ventilation frequency for the factory and for the clean room should be necessary

and realization of industrial applications of compression type heat pump systems would be seriously requested.

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