HEAT PUMPING TECHNOLOGY

—An economical and resource-saving energy solution that protects the environment--

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ABSTRACT ;

Heat pumping technology consists of thermodynamic techniques for transferring heat from a body that is a heat source to a higher-temperature body. The transfer of heat by heat pumping cools the heat source, from which heat is absorbed, and adds heat to the body to which the heat is transferred. That is, a heat pump combines the functions of cooling and heating by nature. The proportion of the quantity of heat that can be utilized as heat output against to the quantity of energy (in terms of heat) that is necessary for operation of the heat pump (heat transfer), is called the coefficient of performance (COP) and serves as an index of the heat pump's operating efficiency. Recent technical progress has brought the value of the COP of air heat source heat pumps for residential use to almost 6, making it possible to put to use a quantity of heat equivalent to 6 times the energy that is consumed in the operation of the heat pump. The COP can exceed 10 in systems that allow the output to be evaluated as the sum of the quantities of heat for the cooling effect and the heating effect, which are the basic functions of heat pumping technology.

In developing countries, where a great increase in demand for energy is expected, it is considered very effective and important, both economically and for resource conservation and protection of the environment, to build up such energy-saving technology, not just in terms of individual items of equipment but also, in future urban infrastructure, as social systems that make it possible to utilize both the cooling and heating functions Recent progress in electric power generation technology is bringing about a power generation

thermal efficiency of 50% or more, and in electrically driven heat pump systems the energy utilization efficiency is improved by the combined effect of an improved COP with greater power generation thermal efficiency. Heat pumping technology is therefore expected to come into wider use in a broad range of applications worldwide as a means of achieving ever more economical energy utilization.

1. INTRODUCTION:

Global energy demand burgeoned in the 20th century, and in the 21st century it is also expected to show great growth, mainly in developing countries. Although per-capita energy consumption in the high-population developing countries of Asia has thus far been smaller than in industrially advanced countries, it is thought that in the 21st century the improved living conditions brought about by economic growth in various countries will increase per-capita energy consumption, and this, combined with a shift in the structure of industry from primary to secondary and tertiary industries, will ensure a considerable increase in the demand for energy. The problems of waste disposal and air pollution as well as other environmental degradation brought about by energy consumption are growing serious even in developing countries. When the energy consumption that is expected to grow ever larger in thickly populated cities is taken into account, the widespread use of heat pumping technology, which is economical while conserving resources and protecting the environment, is considered to be very important.

Moreover, in view of worldwide environmental issues symbolized by global warming, along with constraints on the world's resources, the further development and spread of efficient energy utilization technology is an important common challenge facing industrially advanced countries as well as developing countries.

2. HEAT PUMPING TECHNOLOGY IN JAPAN'S MODERNIZATION

The modernization of Japan has been, among other things, a history of desperately trying to strike a balance between supply and demand in the face of a growing demand for energy. Heat pumping technology was a focus of attention during the era of frequent energy supply shortages. Without public

awareness of the issue of environmental pollution brought about by energy consumption, however, it has had difficulty competing economically with combustion methods, which easily generate heat, and has been no more than an activity carried out by a few pioneers and visionaries.

2.1 The infancy of heat pumping technology up to the Second World War

In the Meiji Restoration (1868), Japan adopted policies to build an affluent country with a strong military by adopting the social systems and modern technologies of the West in a bid to "catch up to and surpass" the modern societies of Europe and America, and since then knowledgeable people have understood that modernization requires an abundant, stable supply of energy.

Realizing the importance of possessing high-density energy sources, in 1872 the government enacted a law to nationalize mineral resources and began government-run coal mining. With the subsequent modernization of industry and the military, the main sources of energy shifted to coal and oil, but civilian dependence on biomass energy remained for a long time.

Having rapidly developed itself into an affluent and militarily strong country, Japan achieved a miraculous victory in its clash with Russia in the Russo-Japanese War, but because it lacked natural resources and was still weak, the great consumption of energy during the war led to a considerable energy shortage within the country. At this time, Dr. Otsuka of Kyoto University suggested the use of heat pumping technology as a way to overcome the energy shortage, and this was the first time that heat pumping technology was introduced in Japan (1926).

The pioneers of heat pumping technology subsequently boldly took on many challenges. Among them, Masanosuke Yanagimachi racked up particularly notable accomplishments in the development of heat pumps in Japan..

However, the experimental or daring attempts of numerous pioneers to use heat pump systems could hardly compete with the easy methods of producing heat by combustion, and with the immaturity of the technology and its reliability problems, only a few visionaries adopted such technology.

In addition to this, under the shadow of war in the 1930s, under the wartime footing not only energy but all resources and labor were concentrated for military purposes. When the State Mobilization Law

came into effect in 1940, civilian demand was strictly limited, and heat pumping technology, although it had begun to grow, was choked off.

2.2 The period following the Second World War

2.2.1 The reconstruction period (1945-1960)

Japan's defeat in the Second World War(1945) meant a devastating destruction of not only industries and the supply of energy but of the very basis for people's lives, with an absolute poverty of energy and materials in all aspects of daily life.

Japanese industry made a phenomenal recovery in a short time, however, thanks to aid from the victor countries and determined and concentrated investment in basic domestic industries. There was relatively little damage to hydroelectric power stations located in remote areas. Hydroelectric power was the main source of electricity in those days, and this was one factor in the early restoration of electricity supplies. Small-scale heat pump equipment was imported from America at this time, but it was used only in a few facilities

Thereafter, Japan entered its period of high economic growth, due in part to the outbreak of the Korean War (1950), which stimulated exports of goods for military uses.

2.2.2 The growth period (1960-1980)

The demand for energy rapidly grew along with the high growth of the economy, and ensuring energy resources and a stable supply of energy to support economic growth became an urgent and crucial challenge for the country. Rising quantities of energy resources, especially oil, were imported from abroad, and dependence on foreign energy resources increased. Air conditioning spread from factories to commercial and office buildings in order to improve productivity, and the foundations were laid for the widespread use of heat pump systems today. That is, heat pumping technology became the foundation for the popularization of cooling and the popularization of heat pumping equipment, for which there is little competing technology in terms of its inherent cooling and heating functions.

The high economic growth raised people's living standards, as air conditioning, along with electrical

appliances, became commonplace in homes and the summertime electric power peak grew higher. In response, power companies, while working on the one hand to develop power sources, also strongly promoted efficient energy use on a company-wide basis and recommended heat storage-type heat pump systems in order to even out electric power loads.

Although the policies giving top priority to economic efficiency, which resulted in this remarkable economic growth, succeeded in expanding trade exports and achieving an enormous trade surplus, they also led to great consumption of energy and natural resources. This led to serious environmental contamination by industrial waste and air pollution, with pollution problems occurring in various parts of the country. As environmental awareness increased, the contradiction was pointed out that even combustion-type air conditioning equipment, which should create a pleasant environment, contaminates the outdoor environment with soot, smoke, exhaust, and other air pollution. Heat pumping technology then became a focus of considerable attention.

Pollution measures in Japan began in earnest with the enactment of the Basic Law for Environmental Pollution Control in 1967.

2.2.3 The period of maturity (1980-1990)

The oil crisis that began in 1974 was a tremendous shock to Japan, which is highly dependent on foreign sources of energy. It was a serious warning that a stable supply of energy is essential for the security of the state, and Japan adopted energy policies encouraging even greater energy efficiency, diversification of energy sources, and technologies for the use of natural energy, including renewable energy.

A Law Concerning the Rationalization of Energy Use (1979) was enacted, and energy-related research such as the Moonlight Project as well as research and development of a super heat pump were carried out.

In 1980, a common strategy of participating member countries was announced by the International Energy Agency (IEA), which was founded to work for a stable supply of international energy. It was proposed that heat pumping technology should be developed and disseminated as a promising technology for the final demand phase, and today's international heat pump conference was born, at which information

is exchanged about the present state and marketability of heat pumping technology in various countries.

2.2.4 The period of reconsideration and groping for solutions (1990-)

The 1990s saw the dawn of an era in which it is asserted, as a problem of global warming, that it is the common responsibility of all humanity to consider how energy is used, while protecting resources and the environment. However, the resource and environmental circumstances, as well as the interests, of different countries often stand in opposition to each other, and consensus about specific means and methods cannot always be achieved. While maintaining the modern basis for life that is supported by energy consumption, humanity is called upon to reflect on how energy is used, and whether to aim for sustainable development. Amid future constraints on resources and the environment, we are groping for major new roles to be played by heat pumping technology in the 21st century.

3. DEVELOPMENT OF HEAT PUMPING TECHNOLOGY

3.1 The technology during the period of growth and development

The construction of air-conditioning equipment following the war began with the use of parts imported from America. A building boom occurred in the 1950s when many new buildings were constructed on sites destroyed during the war, with air-conditioning equipment using many heat pump systems. Among these, the construction of a series of telephone exchange facilities and broadcasting stations, which generate internal heat, was a major event in the development of heat pumping technology. As large heat pump devices, the development of a heating tower system in 1952 using calcium chloride, a heat storage system in 1953, and an air-heat-source heat pump system in 1958 can be cited. However, much of the heat pumping technology at this time was learned from American air conditioning technology, such as the water-loop heat pump system.

In 1958, a succession of electric heat pump package units with air and water heat sources were launched on the market by such companies as Osaka Metal Industries (presently Daikin Industries) and Mitsubishi Electric, serving as an impetus for the wider use of heat pumps in small shops and office

buildings.

The widespread use of such systems today is the result of many subsequent improvements, including a small, split-type room cooler introduced by Toshiba in 1961, its heat pump version and a package-type split version in 1967, a rotary compressor in 1968, a helical-type compressor in 1970, and a scroll compressor in 1984. Following Toshiba's development of an inverter-controlled air-heat-source heat pump in 1981, a multiple version of the air-heat-source heat pump (a system in which multiple indoor units are operated by a single outdoor unit) went beyond the limitations of the previous package-type heat pump to popularize heat pumping technology in medium- and large-size buildings.

3.2. Limitations of previous heat pumping technology and overcome

3.2.1 Weak points of previous heat pumping technology

Previous heat pumps had various weak points, including:

(1) Their initial cost is high.

(2) Time is required until their heating operation commences.

(3) It is difficult to obtain high-temperature output.

Even now, it cannot be denied that heat pumps have a higher initial cost than simple combustion devices. If the cooling function is simultaneously required, however, heat pumps are more economical than combination with a combustion device, and it is considered that the current technology has reached the stage of being fully competitive taking into account the life-cycle cost of combustion devices, including their operation and maintenance costs and the cost of additional devices such as devices to introduce air for combustion, to discharge exhaust gas (and in some cases to treat the exhaust carbon dioxide), and to prevent odor and fires.

With regard to the commencement of heating operation, this is a problem in intermittent operation such as in residential heating. However, this problem has been greatly alleviated in the latest inverter-controlled heat pumps, and methods have been developed such as periodic continuous operation in which a standard minimum temperature is set, and combined use with heat storage systems.

For the output temperature, although it varies with the application, a higher output temperature than

necessary should not be sought, and there is a proper "heat pump temperature range" for using a heat pump. In other words, it is unreasonable to use a combustion system, which generates a high temperature, in order to supply the heat demand in the heat pump temperature range. One must consider the quality of the heat and give thought to the use of the appropriate facilities in the appropriate locations.

3.2.2 Improvement of heat pumping technology and expansion of its range of applications

The first cause of the recent improvement in heat pump performance is the adoption of inverter-controlled rotary compressors. A high thermal head requires high machining precision and high rotation speed, and this has required improvements in such factors as the bearings, refrigerant, and lubricating oil. The machining technology for the latest twin-rotary compressors makes high-speed rotation possible with a narrow clearance, and the expansion of the range of rotational speed control by an inverter has greatly improved equipment performance, durability, and operational reliability and has enhanced overall economy through efficient tracking of load fluctuations throughout the year. Previously, stable and efficient operation of a heat pump had required a heat source and heat sink such as an underground water source having a stable temperature throughout the year. However, recent technological progress has made it possible to achieve stable heating operation when the outdoor temperature is as low as -15°C, even with a heat pump having an air heat source that fluctuates greatly.

Inverter control greatly improves the operating efficiency with a small-capacity heat pump system, and it is hoped that inverter control will be widely applied in the future to large-capacity equipment so as to better withstand voltage and to reduce costs.

Other factors that can be cited include advances in sensor technology, the development of high-performance heat exchangers through clarification of the phenomenon of heat transfer, and improvements in refrigerant control and lubricating oil. Moreover, with the advances made in design theory, air-heat-source heat pumps of the most general design are becoming the most common type in commercial and office buildings and residences, while centrifugal- or helical-type heat pumping systems having heat collection and heat storage systems are often used in large buildings and plant buildings, as well as geothermal supply plants.

Heat pumping technology, which has always provided the functions of both cooling and heating, has

come to be used in many aspects of home life and industry, including heating, cooling, freezing, dehumidifying, distillation, freezing separation, brewing, fermentation, indoor heating, indoor cooling, air conditioning, and hot-water supply, and the range of applications is expected to broaden even further as the economy and efficiency of heat pumping technology are further improved.

4. THE DRIVING FORCE BEHIND THE DEVELOPMENT

4.1 The role of heat pumping technology in various sectors

* Pioneers and visionaries: Taking on the challenge of creating opportunities

As discussed above, at first there were a small number of pioneers who focused their attention on heat pumping technology and advocated its utilization, along with visionaries who understood.

* Manufacturers and distributors: The role of exploring the market

Soon, as the demand for cooling and heating increased, equipment manufacturers on the lookout for commercial possibilities carried out research and development on products that appeared to be marketable, and the results were submitted to the market through the mechanism of distribution.

* Power suppliers: Recommendation for dealing with power peaks

As the demand for air conditioning became widespread and the power peak became sharper, power suppliers set their sights on heat storage systems and electric power load leveling, and actively promoted heat pumping systems, resulting in greater understanding of these systems among consumers.

* Government: Public action initiative

The government recognized heat pumping technology as one way to save energy and to even out power usage so as to ensure a stable supply of energy and prevent pollution, and provided assistance for its research and development and its wider use. A clear statement of intent and initiative by the government is important.

* Companies and consumers that are users: Interest in resource conservation and environmental protection as well as in economy

Companies and consumers need to have the understanding to make choices by an overall assessment

that incorporates not only their immediate economic benefit, but also interest in their own living environment and preservation of the global environment.

4.2 Environment for wider use of heat pumping technology: The heat pump temperature range and the social environment

Tracing the history of the development and popularization of heat pumping technology in Japan, it can be said that a desirable environment for the spread of heat pumping technology includes a social environment that demands resource conservation and environmental protection along with economy, consciousness-raising among consumers, manufacturers that provide highly reliable heat pump equipment and systems possessing the required economy and efficiency, and a government energy policy that sets clear directions.

In 1980, the IEA took up the popularization of heat pumping technology for the more sophisticated utilization of energy as a joint strategy of its member countries. It is considered very significant that one direction for the development of world energy utilization technology has been shown by this international heat pump conference, where since 1984 information has been exchanged about the state and marketability of heat pumping technology in various countries and discussions have been held on its role in energy policy.

5. FUTURE PROSPECTS FOR WIDER USE OF HEAT PUMP

5.1 The heat pump as an individual item of equipment: The stage of introduction, and ensuring its reliability

In order to quickly deal with the various problems that may be encountered in equipment performance and maintenance when it is first introduced and one cannot be sure of its reliability, it is desirable during this introductory period to begin its introduction from industrial processes whose maintenance is well monitored and at locations where there is a good maintenance control system. Heat pumps should be installed first in commercial and office buildings, and finally in residential buildings. It is generally risky to seek to install them in residential buildings from the beginning. In residential buildings, heat pumps

might be used in completely unanticipated ways, and once they cause dissatisfaction, it takes a great deal of time and effort to resolve the matter.

Standardization and a system of common performance tests by manufacturers' organizations are effective for popularizing heat pumps as individual items of equipment, and a top runner system (in which a public body annually publishes each manufacturer's performance) is effective for improving performance.

5.2 Heat pumping systems incorporated in social systems

What is currently lacking in the environment for popularizing heat pumping technology in Japan are measures for building and maintaining heat pumping systems as social infrastructure for fostering pleasant urban living.

In order to maximize both the heating and cooling functions of heat pumping technology, it will be very effective, for the sake of both energy utilization and the urban environment, to adopt as social systems those systems in which diversity and temperature diversity can be maximized for the heat demand of various buildings located in a city.

5.3 Creating a social consensus

Energy cannot be used at 100% efficiency. Energy consumption entails unavoidable waste heat and waste products. The urban environment, which serves as the heat sink for this waste heat, warms up. Specifically, the heat is discarded in the city's air, sewage, soil, underground water, rivers, and the seashore into which the rivers flow. It is important to have people understand that energy consumption for their comfort and convenience has the result of fouling their own environment; to use energy as efficiently as possible; to make it more widely known that heat pumping systems are useful for preserving the urban environment as well as for the economic benefit of recovering urban waste heat; and to build a consensus that highly unnecessary (and expensive) high-temperature heat (combustion heat) should not be used for heat demand in the heat pump temperature region.

Conclusion:

In the broad utilization of energy, we should take on the challenge of the further development and wider use of heat pumping technology, for economy, resource conservation, and environmental protection.

(1) Heat pumping technology is superior in terms of both economy and environmental protection, and the demand in the heat pump temperature region can be covered by heat pumping technology.

(2) In order to further enhance the usefulness of heat pumping technology, systems should be built that take full advantage of both the cooling and heating functions that are an integral part of heat pumping technology.

(3) In creating a pleasant urban living environment, the wider use of heat pumping technology should be promoted as a policy matter, as a social system for effectively utilizing the time and temperature diversity of the heat demand for buildings and facilities of various kinds.

Heat pumping technology is expected to spread and develop further in various countries of the world, and to contribute to world resources and their preservation.

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