Examples and Future Prospect of Heat Pump Application Technology Conducive to Solution of Food, Energy and Environmental Problems

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Abstract

It is assumed that the 21st century will be a century of human struggle for survival. Particularly notable is a pressing need to successfully deal with the problem of food shortage that will be brought forth by expected growth of population in the world, especially Asia and Africa. A primary consideration in solving this problem is not only to increase food production but also to reduce losses from the disposal of wastes. Among promising solutions is heat pump application technology that is useful in increasing the yield of farm produce and keeping the freshness of gathered crops. Much is expected of this technology which has already established a fine track record of successful use in many instances, contributing to environmental preservation and the improvement of agriculture in Japan. This report first describes some specific results of effectively using the technology by taking up the following examples and then discusses its future prospects.

- Year-round culture of vegetables at facilities equipped with heat pump air-conditioning systems using hot-spring water, etc. as a heat source
- Industrial production of mushrooms in protected facilities using ice thermal storage air-conditioning systems
- Milking device using a waste heat recovery heat pump
- Dehumidifier/dryer system using a heat pump
- Low-temperature high-humidity storage of farm produce by wet air cooling system
- High-value-added flower production by soil cooling with an ice thermal storage cold water supply system

Background

In February 2001, the United Nations published a forecast that the world population will increase 52% over the present level to 9.3 billion by the year 2050. The forecast indicates that 8.2 billion people - 88% of the total - will be concentrated in Asia and Africa.

The growth of population may cause a food shortage. To avoid such a situation, it is expected, greater importance will be attached to technologies to increase food production and reduce losses from waste disposal. On the other hand, expansion of food production is predicted to cause a series of problems linked with one another, such as higher energy consumption and increased emissions of environmental load substances, particularly carbon dioxide.

Under these circumstances, what we should aim to attain toward the future is to develop and widely diffuse the technologies, specifically those for increasing food production, which will minimize energy consumption and environmental-load emissions. The heat pump is one of the promising technologies that can fully meet these requirements.

Carbon Dioxide Emissions from Japanese Agriculture

An estimation shows that more than 97% of environmental load emissions from the agricultural sector is ascribable to energy consumption (Sakai 1998). Much of energy consumption in this sector comes from the facilities to grow vegetables, fruit trees, flowers and ornamental plants, and other garden crops, which account for 34% of the total agricultural production in Japan. Another major category of energy consumption comprises the facilities to raise livestock that accounts for 23% of the nation's total agricultural production. By type of energy, according to the estimation, some 90% of the total energy consumption in the farming sector is represented by fuels, including gasoline, kerosene, gas oil and fuel oil, with the remaining 10% or so represented by electricity. Most of energy consumption at greenhouse and other protected cultivation facilities is for air conditioning to artificially adjust the environment in these facilities.

On one hand, farming in protected facilities contributes to the improvement of productivity as it can grow crops and livestock without being affected by seasonal or regional constraints, while on the other hand, it brings forth increased emissions of CO_2 and other pollutants resulting from higher energy consumption. Considering that most of the emissions come from fuel consumption, it is important to efficiently use those energy sources which have a low CO_2 emission intensity per unit of output.

Also notable is the existence of many distribution processes from the supply sources of farm produce to final consumers. The key point in these distribution processes is the maintenance of product quality because failure to maintain the quality of farm products would result in the loss of their commercial value and consequently in their disposal as wastes. An important factor in maintaining the quality of farm products is to properly control the temperature, humidity and gas composition of their surrounding environment. In other words, it is essential that these elements be controlled optimally according to the types and properties of the products. In view of the need to reduce the emissions of CO_2 and other environmental load substances, interested parties came to conduct studies in recent years to find optimal conditions for energy input aimed to adjust the temperature, humidity and gas composition of the environment inside these production facilities and for losses from the disposal of waste farm products in distribution systems (Siina 1998). Apparently, increasing importance will be attached from now on to the development and diffusion of technologies to reconcile the reduction of losses from the disposal of waste farm products with energy conservation.

Commitments of Tokyo Electric Power Co.

- **Commitment as Electric Energy Supplier**

Tokyo Electric Power Co. has taken various measures to preserve resources and arrest global warming while fulfilling its responsibility for meeting public interest requirements, i.e., securing a stable supply of energy.

Fig. 1 shows the trends of CO_2 emissions and CO_2 emission intensity per unit of electricity sales at TEPCO. Since 1970, the company reduced its emission intensity to about half by fiscal 2000. This was attained by such measures as increased use of non-fossil energy, particularly nuclear power generation, and the improvement of thermal efficiency in thermal power generation. Through these measures, our energy consumption for power generation decreased to approximately 5,600 kJ/kWh (1,300 kcal/kWh) in primary energy equivalent (Tepco 2001). It may be argued, therefore, that the replacement of a heating and cooling method based on fuel combustion by heat pumps, which have a higher coefficient of performance, will lead to energy conservation and a reduction of CO_2 emissions.

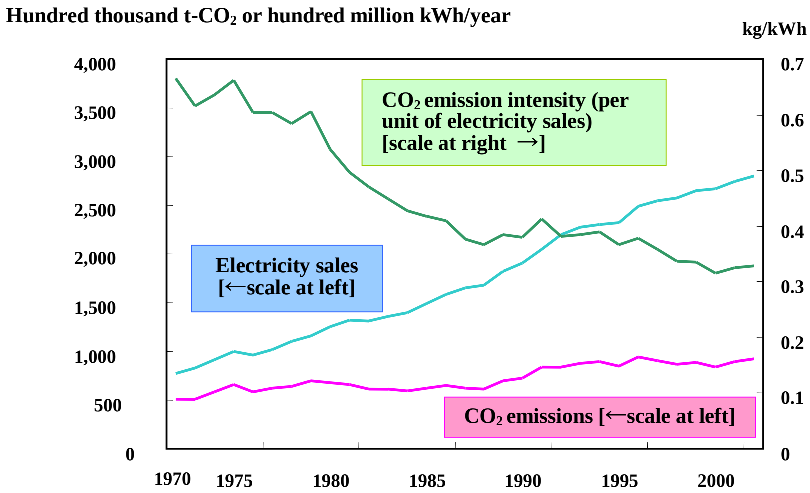

Fig. 1 Trends of CO_2 Emissions and CO_2 Emission Intensity (per Unit of Electricity Sales) at TEPCO

Table 1 shows the CO_2 emission intensity at TEPCO as divided into the daytime (from 8:00 to 22:00) and the nighttime (from 22:00 to 8:00). As is apparent from the data, the CO_2 emission intensity in the nighttime is around 78% of the intensity in the daytime. This is due to a low ratio of power generation using fossil fuel in percentage of total and a reduction of transmission losses during the nighttime (Tepco 2001). Accordingly it is expected that increased use of nighttime power service will lead to a further reduction of CO_2 emissions. From these findings, TEPCO has committed itself to carry on research and development activities for thermal storage systems and, in addition, offer electricity rate options that reduce electricity charges when customers use thermal storage systems.

Table 1. Tepco's CO_2 Emission Intensity (Per Unit of Electricity Sales)

	CO_2 (kg-CO_2/kWh)
Annual average	0.33
Daytime (8:00～22:00)	0.35
Nighttime (22:00～8:00)	0.28
Day:night	100:78

- **Commitment to Further Diffusion of Heat Pump Technology in Agricultural Sector**

Reportedly the use of electricity in the Japanese agricultural sector began with the application of electric pumps in 1902 to the irrigation of paddy fields. Around 1970, experimental studies began to be conducted on the use of refrigerating machines and heat pumps for agricultural production. Since then, these equipment have made cold water, cold air, hot water and hot air readily available for this purpose, and their utilization technologies have been developed and commercialized in various fields, including protected horticulture, mushroom cultivation, crop storage and dairy farming.

During the period from the initial use of electricity in the agricultural sector up to now, TEPCO has provided many pieces of information as a step toward further diffusion of efficient use of electricity through the activities of the Japan Association of Agricultural Electrification (JAAE) and other interested organizations. For example, the company provides a program to officially commend those who use electricity efficiently and to praise their meritorious services, while offering relevant information widely among the public. Other commitments of the company include activities to regularly hold seminars and group technical tours on efficient use of electricity in the farming sector and to collect and publish examples of efficient electricity use.

Examples of Heat Pump Technology Applications in Japanese Agriculture

- **Year-Round Culture of Vegetables at Facilities Equipped with Heat Pump Air-Conditioning Systems Using Hot-Spring Water as Heat Source**

This example concerns a demonstration test conducted in a bid to develop a protected facility capable of stably growing fresh vegetables in Hokkaido even in winter (Watanabe 1989). It is difficult to grow vegetables in the natural environment in winter at the place where the experimental facility is located as the area is exposed to severe weather conditions in the season, including an atmospheric temperature of -10℃ or lower, heavy snow and low insolation.

Fig. 2 shows the configuration of the facility, which consists of a 97-square-meter control building and a 132-square-meter glassed greenhouse for vegetable cultivation. The greenhouse uses 4 mm thick glass to prevent damage from falling icicles. It is also provided with double curtains for thermal insulation and with high-pressure sodium lamps to make up for inadequate insolation. As there is a hot spring sending forth warm water of about 40℃ in this area, the facility uses hot-spring water at a flow rate of 100 ℓ/min as a heat source for air heating. The air-conditioning system installed at the facility is designed to keep the temperature in the greenhouse at about 20℃ even when the outside temperature drops to -15℃. The system is equipped with two 5.5-kW (compressor power) heat pumps and one 7.5-kW heat pump.

Fig. 3 shows the temperature in the greenhouse on the day when the heating-related load reached the annual peak. Temperature low on the day was - 19℃ and the maximum heating load was around 40 Mcal/h but, as indicated in the diagram, the temperature in the greenhouse at night was maintained approximately at the design level by the operation of two heat pumps. The heat pumps’ coefficient of performance (COP) during heating operation was somewhere between 3.3 and 4.1.

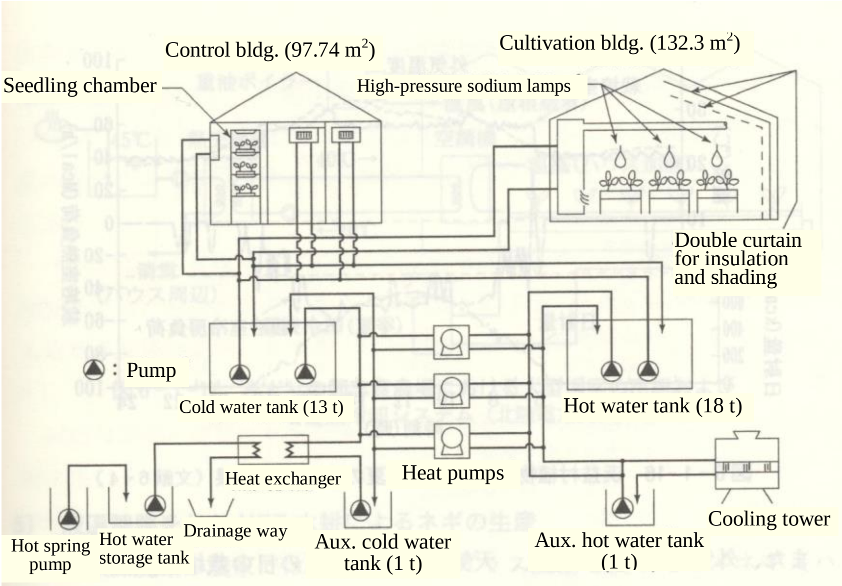

Fig. 2　Outline of System Configuration

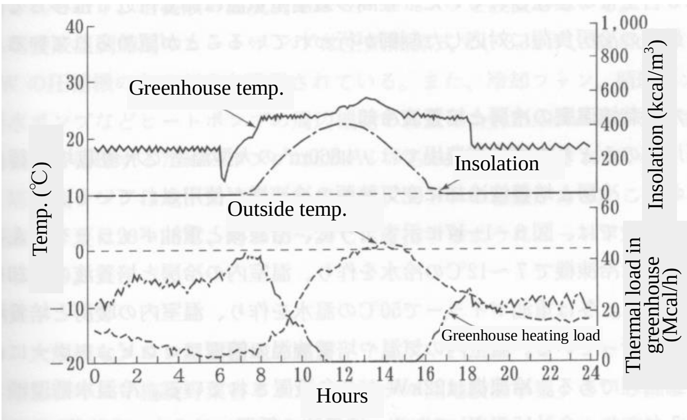

Fig. 3　Thermal Environment in Greenhouse on Heating Load Peak Day

During the experiment, arrangements were made to grow spinach in winter and lettuce in spring.　It was found that the quality of these two items met the marketability standards.

- **Industrial Production of Mushrooms in Protected Facilities Using Ice Thermal Storage Air-Conditioning Systems**

This example relates to a protected facility that artificially grows maitake mushrooms throughout the year using an ice thermal storage air-conditioning system (Tepco 2002). Maitake is a mushroom with a very high rarity value that is sensitive to temperatures and humidity and, under natural conditions, rarely grows in coniferous forests at more than 600 m above the sea.

Fig. 4 shows the maitake cultivation processes. Particularly important of these processes is the growing stage at which the temperature and humidity in the growing room have to be accurately controlled. An ice thermal storage air-conditioning system, installed in a growing room with a total space of about 1,800 m^2, controls the indoor temperature and humidity at 20℃ and 90%, respectively. The humidity is controlled by operating humidifiers, whenever necessary. An internal view of the growing room is shown in Fig. 5. This facility ships out maitake at a rate of 3 t/day.

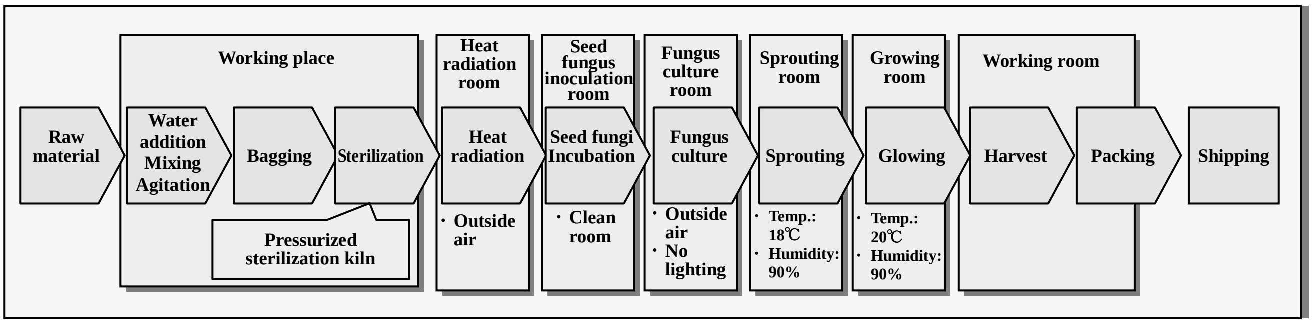

Fig. 4 Maitake Production Processes

Fig. 5

The ice thermal storage air-conditioning system is operated to cool the rooms from April to October every year. The system makes ice in the thermal storage tank by operating the refrigerating machine in the nighttime (from 22:00 to 8:00) and cools the rooms in the daytime (from 8:00 to 22:00) by melting ice and sending cold water thus prepared into the air-conditioning machine. Most of electricity supply for the system is consumed for operating the refrigerating machine at night.

● Milking Device Using Waste Heat Recovery Heat Pump

This device cold-stores raw milk from dairy cows until it is gathered for delivery. Structurally, the device combines an ice thermal storage bulk cooler and a water heater that recovers waste heat from a refrigerating machine as a heat source (Murano 1998).

The configuration of the device is shown in Fig. 6. With this device, raw milk from milking is no longer exposed to quality degradation risks from the propagation of miscellaneous germs as it is immediately stored in a bulk tank that is cooled by cold water from 35℃ to 4℃.

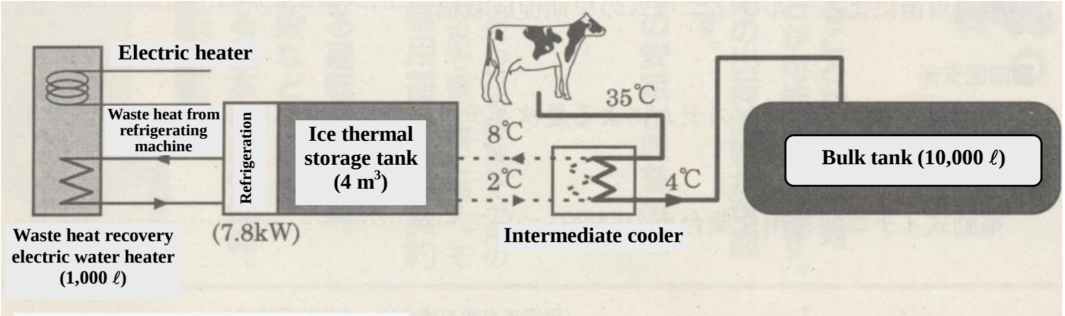

Fig. 6 System Configuration

The device stores ice by operating the refrigerating machine in the nighttime, while in the daytime, it prepares cold water by melting the stored ice and supplies it to the heat exchanger. At the same time, the device stores hot water in a hot water tank using waste heat recovered from the refrigerating machine. The hot water tank is equipped with an electric heater to increase the temperature of recovered warm water to 85℃. The hot water is used for cleaning dairy cows and milking units.

- **Dehumidifier/Dryer System Using Heat Pump**

The dehumidifier using a heat pump consists of an evaporator and a condenser housed in one case, as shown in Fgi.7. In this system, humid air is sent into the case and dehumidified while it is passing through the evaporator. The dehumidified air is heated while it is passing through the condenser and then it is sent into the drying chamber.

In drying food or some other products, it is said, a general hot air drying process has a capacity of about 1 kg/kWh in terms of a water extraction rate per unit calorific power while a heat pump drying process has a capacity of around 5 kg/kWh (Okano 1999).

The proposed heat pump dehumidifier has a wide area of applications, including the dehumidification and drying of farm products, such as unhulled rice, root and tuber crops, and flowers and ornamental plants, processed foods including raw noodles, and such materials as lumber.

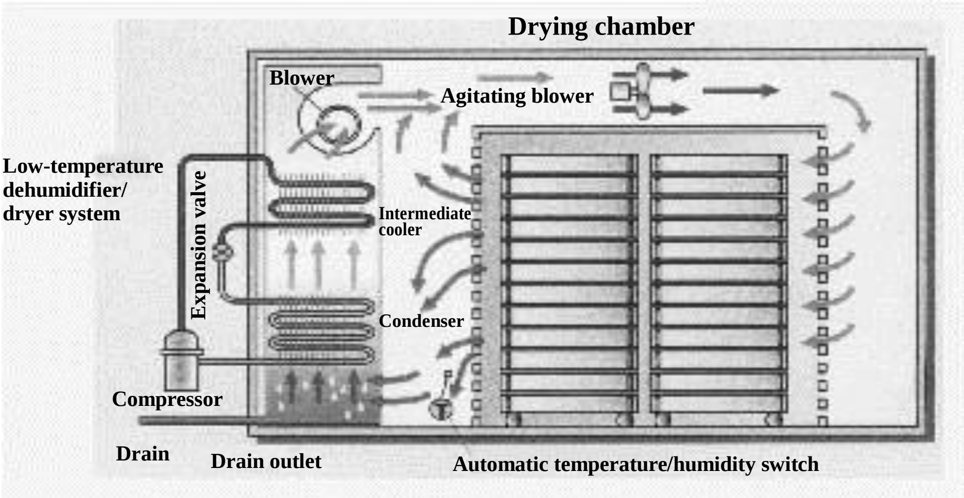

Fig. 7　Outline of Heat Pump Dehumidifier/Dryer System

- **Low-Temperature High-Humidity Storage of Farm Produce by Wet Air Cooling System**

The proposed wet air cooling system is an integrated unit that combines an ice thermal storage tank with a built-in ice making coil, and an air conditioner with a built-in heat exchanger for directly contacting water and air by filling agent. A diagram of its working principle is shown in Fig. 8. Since the wet air cooling system cools air by bringing it into direct contact with cold water, the system features a function to make air saturated immediately after this process. Saturated air has the effect of arresting the drying of farm products and the resultant loss of their weight. In addition, the wet air cooling system has great environmental preservation capability as it makes ice thermal storage by nighttime power service that has low CO_2 emission intensity.

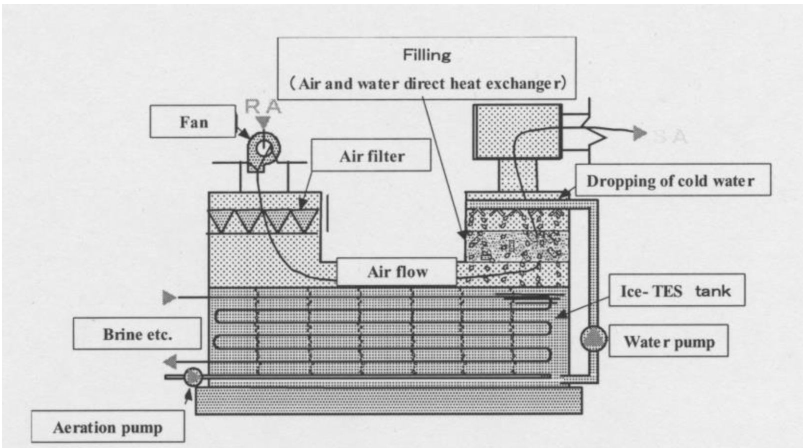

Fig. 8　Principle of Ice Thermal Storage Air-Conditioning System

Fig. 9 shows the results of a low-temperature storage test on loquats, Eriobotrya japonica. The findings indicate that the proposed wet air cooling system involves a smaller weight variation than the direct expansion type dry air system widely used for conventional low-temperature storage facilities (Murakami et al. 2000). Besides, the new system has proved effective in low-temperature storage of cabbages, Chinese cabbages, tomatoes, pears, etc.

(Imakiire et al. 2001) and it is expected that the system will be applied to a wider variety of farm products in the years ahead.

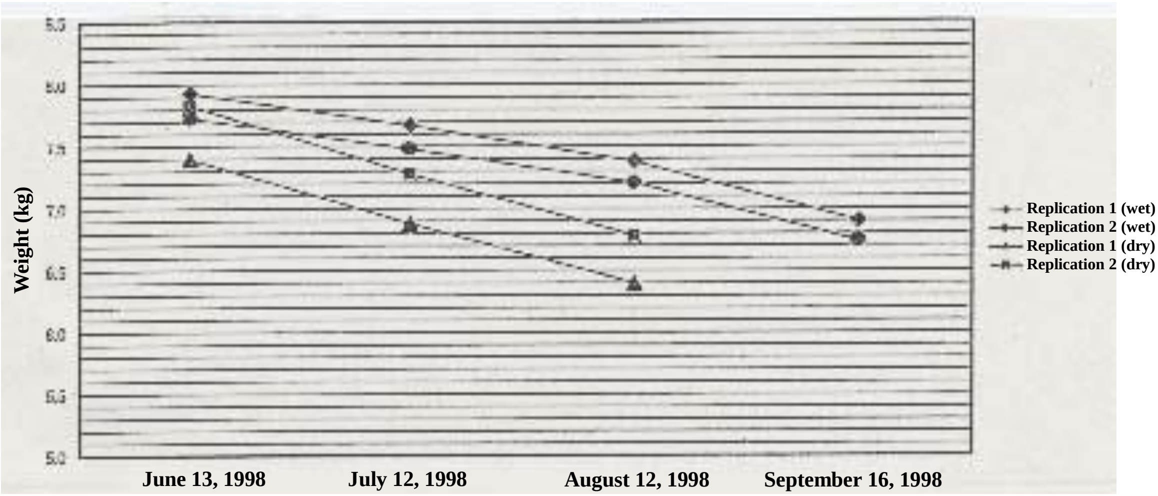

Fig. 9 Variations in Weight of Loquats during Cold Storage

- **High-Value-Added Flower Production by Soil Cooling with Ice Thermal Storage Cold Water Supply System**

This system cools soil around plant roots in glowing alstroemeria and other flowers. As this function accelerates flowering, the system makes it possible to control the shipping time of flowers (Arai et al. 1998).

The configuration of the system is shown in Fig. 10. The system, consisting of an ice thermal storage unit and underground cooling pipes, makes ice in the thermal storage tank at night and supplies cold water from the tank to the cooling pipes in the day. The temperature of cold water supplied to the cooling pipes is set at 5 - 7℃ to keep the soil temperature between 17℃ and 20℃. Fig. 11 shows variations in soil temperature. The ice thermal storage unit is a combination of a 7.5-kW compressor and a 3.8-m^3 ice thermal storage tank which controls the soil temperature in a greenhouse with a space of about 900 m^2.

It is expected that in addition to alstroemeria, the ice thermal storage soil cooling system will be applied to greenhouse cultivation of mandarin oranges and other farm products.

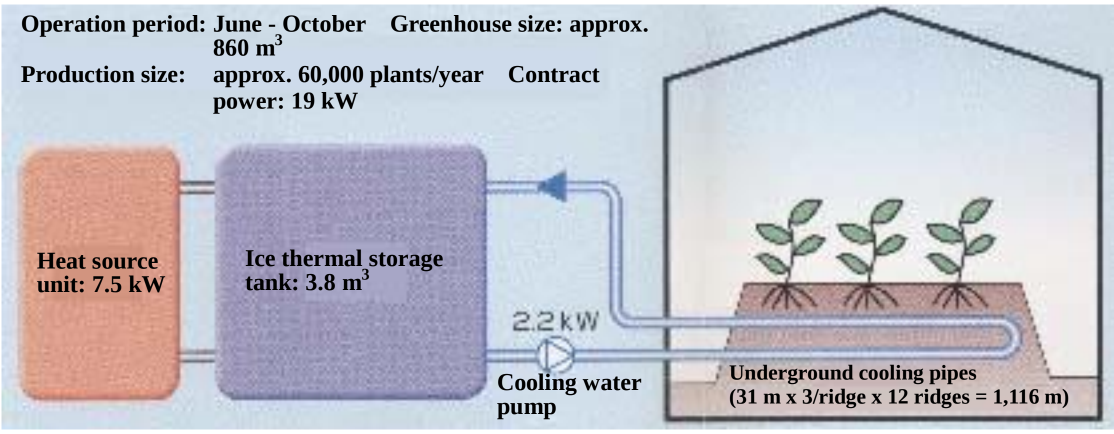

Fig. 10 System Configuration

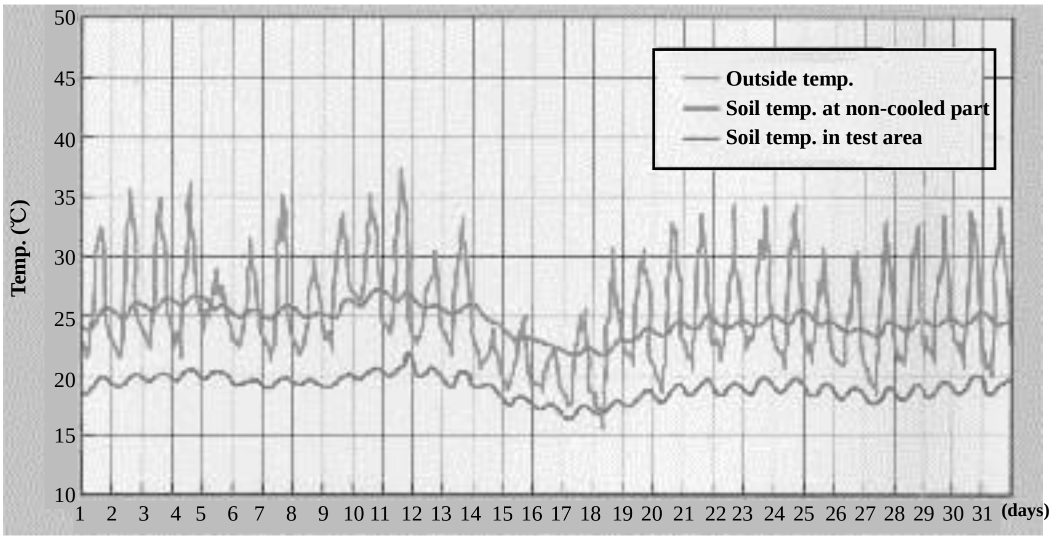

Fig. 11 Variations in Soil Temperature in Summer (August)

Conclusions

The number of facilities for growing vegetables, fruits and other garden crops is increasing year by year in Japan. The cultivation of crops at protected facilities is considered a form of agriculture essential to increasing the production of food as it has an advantage in raising the yield per unit area and maintaining stable output throughout the year. Most of energy consumption at protected facilities comes from the use of fuel for heating and cooling purposes and, in view of increasing importance attached to energy conservation and environmental acceptability, it is desirable that direct use of fuel will be replaced by heat pumps in the years ahead.

Similarly, we believe, a greater hope will be placed on heat pumps in the future as a result of recent activities, specifically studies that began in recent years to optimize the relationship between energy input in farm product distribution systems and losses from the disposal of waste farm products.

In dealing with the energy-saving capability and environmental acceptability of heat pumps, meanwhile, it is necessary to examine not only the performance of heat pumps themselves but also the primary energy-equivalent value and CO_2 emission intensity of electricity required to operate these equipment. Only with a total study of these two factors, we can properly discuss energy conservation and environmental load reductions in society as a whole.

From this point of view, we believe that the tasks to be carried out from now on involve the following three points: first, further improving the performance of heat pumps themselves; second, further accelerating the development of heat pump application technologies for agriculture; and third, minimizing the primary energy-equivalent value and CO_2 emission intensity of electricity required in an effort to enhance energy-saving and environmental-improvement effects resulting from the introduction of heat pumps.

The 21st century is said to be an age of food, energy and environmental issues and, we believe, the heat pump is a technology to offer an integrated solution to these problems. In this context, we hope that heat pumps will come into wider use in the years ahead.

References

Naoki Sakai, Prospects for Production and Reduction of Carbon Dioxide in Greenhouse Agriculture, Abstract of Speech at 13th Agricultural Structure Study Group Meeting, July 1998

Takeo Siina, Optimization of Distribution Systems with Consideration to Environment Load Reductions, Abstract of Speech at 13th Agricultural Structure Study Group Meeting, July 1998

Tokyo Electric Power Co., Environmental Action Report 2001, July 2002

Kanji Watanabe, Constant Cultivation of Spinach and Lettuce in Cold Districts, Special Edition of Agricultural Electrification, Vol.42-10, pp2-8, Japan Association of Agricultural Electrification (JAAE), 1989

Tokyo Electric Power Co., Home Page, 2002

Murano, Economic Effect of Introducing Ice Thermal Storage Systems into Dairy Facilities, Special Edition of Agricultural Electrification, Vol.51-10, Japan Association of Agricultural Electrification (JAAE), 1998

Toshiaki Okano, Reality of Heat Pump and Thermal Storage Use in Agriculture, Japan Association of Agricultural Electrification (JAAE), 1999

Hiroshi Murakami et al., Low-Temperature Storage of Agricultural Products with Wet Air Cooling System, Special Edition of Agricultural Electrification, Vol.53-10, Japan Association of Agricultural Electrification (JAAE), 2000

Hirokazu Imakiire et al., Vegetables Cleaning/Cooling System using Ozone Dissolved Cooling Water, Refrigeration vol. 76-880, JSR&ACE, 2001

Hideaki Arai et al., Study of Thermal Storage for Soil Cooling Growing System for Alstroemeria, Special Edition of Agricultural Electrification, Vol.51-10, Japan Association of Agricultural Electrification (JAAE), 1998