FEASIBILITY STUDY ON THE UTILIZATION OF GEOTHERMAL HEAT PUMP (GHP) SYSTEMS IN JAPAN

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ABSTRACT

Low-enthalpy geothermal resources have not been utilized to their potential in the past. However, since vast tracts of low-enthalpy geothermal resources exist as energy in the form of differential temperatures, the reserves are estimated to be enormous. As a result, there is growing interest in using this untapped energy in order to reduce carbon dioxide emissions which are the main cause for global warming, one of today's most serious issues as addressed by the U.S. Department of Energy and Environmental Protection Agency documents (e.g., EPA, 1993).

The purpose of this feasibility study is to investigate the different aspects of the problem with respect to cost, technology and measures affecting the introduction and widespread acceptance of geothermal heat pump (GHP) systems. Specifically, the study was conducted by collecting information from relevant literature, random surveys, discussion forums and expert groups.

STATUS OF THE GHP (GEOTHERMAL HEAT PUMP) SYSTEM

The GHP system is grouped under the following three systems on the basis of the objective or the manner in which heat is extracted (Kavanaugh, 1991; Oklahoma State University, 1997; GeoExchange, 1998).

- Earth heat exchanger (earth-coupled heat exchanger) type heat pump system. This type of heat exchanger can be placed vertically in boreholes or in shallow trenches, approximately 2 meters deep.
- Heat pump system using ground water directly.
- Heat pump system using surface (lake, marsh or river) water directly, or using it as the heat source. This system requires a series of coiled tubing to be placed into the appropriate lake, marsh or river.

The system to be examined in this survey is "one using a vertical ground heat exchanger type heat pump system (Figure 1)." It could be of the horizontal installation type (horizontal ground heat exchanger type) or the vertical installation type (vertical ground heat exchanger type) depending on the arrangement of the heat exchanger.

Many space heating and cooling systems utilizing the GHP system are being used worldwide, especially in the USA, Switzerland and northern Europe. The approximate (minimum) number of installed facilities includes 300,000 sets in the USA, 20,000 in Switzerland and 30,000 in northern Europe. While most of the systems are for single-family housing in Switzerland and northern Europe, many have been installed in large buildings in the USA. Since one heat pump might be sufficient for a house or large building, the number of installations does not necessarily correspond to the number of users, particularly in the USA (Rybach et al., 1992; Rybach and Eugster, 1997).

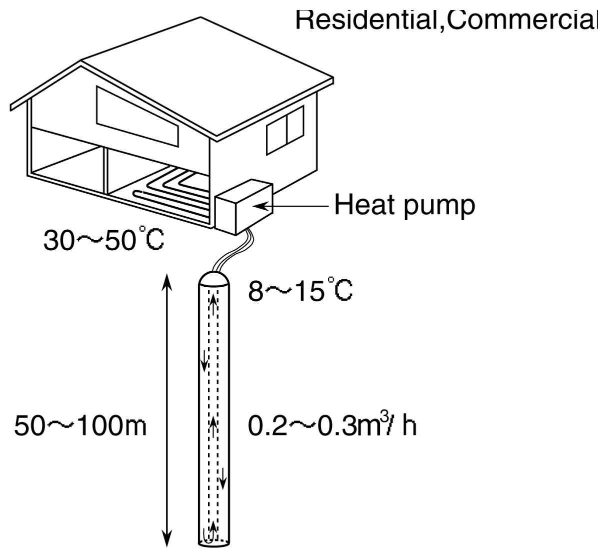

Figure 1. ***General layout of a GHP system using a borehole heat exchanger.***

COST PERFORMANCE EVALUATION AND THE EFFECT OF AN INCREASED USE OF GHP SYSTEMS

Cost Performance Evaluation

The status of the research, development and utilization of GHP systems in Japan has been described by NEDO (New Energy Industrial Comprehensive Development Organization)(1999). The cost of these systems was compared with that of other space heating and cooling systems in Switzerland. A comparison with conventional systems in Japan has also been made.

These studies indicate that if the use of GHP systems becomes more popular, it will reduce the cost of drilling boreholes for the vertical ground heat exchangers, which is the main cause of the high initial cost. If also a 50% subsidy is obtained from the government to promote the introduction of these systems, the installation investment for the geothermal heat pump can be recovered in about two years. In addition if a 30% subsidy is assumed, the increased cost (i.e., the cost difference with respect to a conventional system) can be recovered in less than 10 years. If the cost over the life cycle of the system (i.e., 24 years) is considered, a savings of 2,050,000-3,490,000 yen (approx. a US$ 19,000 to 32,000) can be achieved assuming a 30% subsidy.

Table 1. Initial and operating costs of existing heating, cooling and hot water supply systems, compared with those of GHP systems installed an elderly peoples' home. Investment cost for facilities to lower carbon dioxide emissions. Carbon dioxide reductions associated with the installation of GHP systems in 10,000 homes for elderly people (1 US$ = 110 Yen–approx.).

		Existing system	GHP system		Cost difference	Number of years required for recovery of costs	Necessary subsidy rate for the assumed time of recovery (%)	Carbon dioxide reduction (ten thousand tons/year), Facilities investment		Facilities investment
Construction costs of an elderly peopleÆs home	Heating, cooling and hot water supply systems	Direct oil combustion/absorption type water heater/cooler (two units) (Capacity: 181,440kcal/h)	Heat pump (60 refrigeration tons capacity: 2sets) (Underground heat exchanger (200m: 17 sets) (inclusive of the drilling cost)				For 10 years	(ten thousand yen/ton)	(%)	(ten thousand yen/ton)
	Initial costs	20.05million yen	Without new subsidy	37.2million yen	17.15million yen	28	30	80	0.07	30 (18 with new subsidy)
			With new subsidy	18.6millon yen	−1.45million yen	0				
	Operating costs	2.9millon yen/year		2.3million yen/year	0.6million yen/year	?				
2/3 subsidy available	Initial costs	6.68million yen	Without new subsidy	12.4million yen	5.72million yen	9.5	0			
			With new subsidy	6.2million yen	−0.48million yen	0				
	Operating costs	2.9millon yen/year		2.3million yen/year	0.6million yen/year	?				

Table 2. Comparison of life-cycle costs (LCC) of existing and GHP systems described in Table 1 (for a 50-year evaluation period)(1 US$ = 110 Yen).

		1) Unit cost (ten thousand yen)	Life of the system	Number of systems	Number of years for the evaluation	Number of system replacements	LCC Note 3 (ten thousand-yen/ 50 years)	Total (a hundred million yen/50 years)	LCC difference (million yen/50years)
3) Existing system	2) Oil supply facilities	265	10	1	50	5	1325	2.45	
	Boilers	775	10	2	50	5	7750		
	Piping	190	10	1	50	5	950		
	Operating cost	290	–	–	50	–	14500		
4) GHP system	Heat pump	490	10	2	50	5	4900	1.99	0.45
	ground heat exchanger	2550	50	1	50	1	2550		
	Plumbing system	190	10	1	50	5	950		
	Operating cost	230	–	–	50	–	11500		

If a GHP system is installed in the home of the elderly where many people are living, the amount added to the initial cost can be recovered in 9.5 years, by applying **the existing government subsidy for this type of homes (i.e., 2/3 of the home construction costs).** If a 7% subsidy to promote the introduction of GHP systems is assumed, the additional can be recovered in 5 years (Table 1). A cost **reduction of 0.45 million** yen (US$ 4,000) can be achieved over the life cycle of the home (50 years) if no subsidy is applicable (Table 2).

Benefits of Using GHP Systems

The benefits resulting from the installation of large numbers of GHP systems are:

- Reduction in carbon dioxide emissions,
- Lower heat radiation from urban areas, and
- Decrease in peak power demands.

Regarding the first benefit, if all households in Japan would use the GHP system, the annual CO_2 emissions would be lowered by 52 million tonnes (a 4.3% reduction with respect to the 1990 emissions in Japan; Table 1). Since almost no waste heat is discharged to the atmosphere, the use of these systems is expected to contribute to a reduction of the heat island effect. It would also lower the demand for peak power.

TECHNICAL ADVANCES NEEDED FOR FUTURE GHP SYSTEMS

The following technical advances were considered to make GHP systems more effective and attractive in the future:

- Improvement of the performance of heat pumps, particularly for single-family housing.
- Selection of a heating and cooling system that is most suitable for GHP systems.
- Development of a highly efficient vertical ground heat exchanger.
- Implementation of new tools and techniques to reduce drilling costs.
- Preparation of drilling manuals.

Although there are no serious technical problems associated with the GHP systems, the most important projects to be considered to reduce their costs are the development of small-sized, highly mobile drilling rigs designed primarily for heat- exchanger holes, and the preparation of drilling manuals (items d. and e. in the list above).

TASKS TO ASSIST IN THE INTRODUCTION, PROMOTION AND WIDESPREAD ACCEPTANCE OF GHP

To promote the widespread introduction of GHP systems, the establishment of a support system is very important. This system should be primarily directed toward:

- **Basic Research**
  New developments to improve the thermal efficiency of vertical ground heat exchanger are expected in the future. While the basic studies on this subject have been mostly completed in Europe and the USA, presently in Japan the lack of the subsurface data needed to install vertical ground heat exchangers may slow down the introduction of GHP systems. The collection of such information is urgently needed.

- **Applied Research**
  Applied research on the use of GHP systems has also been mostly done in Europe and the USA, where the main efforts have been directed toward their introduction in different regions. On the other hand, in Japan the most urgent tasks to be undertaken are the standardization of systems, preparation of technical manuals, and testing the reliability of the systems by conducting demonstrations.

- **Promotion Activities**
  GHP promotion centers should be created. Their activities should include solving the various problems associated with the installation and use of GHP systems and for the preparation of subsidiary systems.

Basic Research – Development of Subsurface Temperature, Groundwater level and Geologic Maps for an Optimal Design of Borehole Heat Exchangers

A characteristic of the GHP system is that its heat exchanger is installed in boreholes. The installations above the ground surface are similar to those of conventional heating and cooling systems. Therefore, it is important to obtain the information necessary for designing and estimating the cost of the vertical ground heat exchanger. It must be made clear that all associated studies should consider the prevailing conditions (climate, topography, geology) of Japan, as well as the distribution of a) subsurface temperatures, b) geothermal gradients, c) soil thermal conductivities and d) groundwater flow conditions.

Besides the need to obtain the thermal gradient down to 100 m depth (Figure 2), data on the groundwater levels and, if possible, the groundwater flow direction and rate are very important. The design of vertical ground heat exchanged can be made easy if maps with the required information are available. Sometimes, the lack of adequate information results in an unnecessarily conservative design.

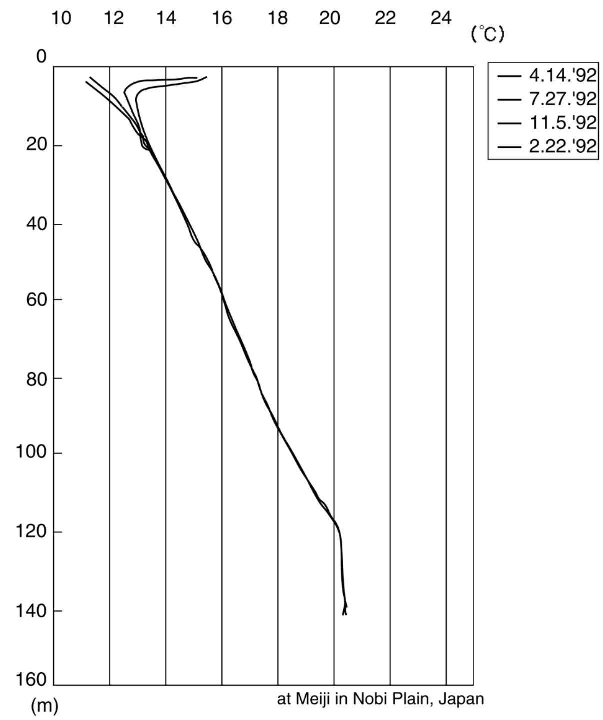

Figure 2. ***An example of downhole temperature logs.***

Appropriate geological information about the area where the vertical ground heat exchanger is going to be installed (less than the 100 m deep) allows the preparation of adequate drilling cost estimates. The data should include information on the presence of conglomerate layers, faults or bedrock (Marui, 1997; Uchida, 1998).

Applied Research - Standardization of the GHP System and Preparation of Manuals

To promote the installation of GHP systems, all the parties involved, including designers and system builders, must share common recognition and understanding of the system. This requires standardization of the system and preparation of manuals. By designing and installing GHP systems in accordance to the manuals the quality can be properly controlled and a high level of reliability assured.

The standardization of GHP systems and the preparation of manuals should be made as soon as possible also in Japan. In the USA, these activities are being promoted primarily by IGSHPA (International Ground-Source Heat Pump Association at Oklahoma State University) with the cooperation of universities, scientific societies and national laboratories.

The introduction of manuals already completed in Europe and the USA is considered very helpful to promote the systems in Japan. Therefore for the time being, we should introduce the overseas technologies and determine which are adequate for Japan and where to make additions and changes.

Promotion Activities - Demonstrations, Promotion Centers and Subsidy Program

- **Demonstration of GHP Systems**

  Demonstrations are extremely effective for recognizing the advantages and points of excellence of the GHP system. It is important to summarize the results of the demonstrations in case studies reports and to be used in promotion activities.

  At this time and for this study, a number of elderly peoples' homes will be selected as the demonstration targets. The selected types of homes shall be such that:

  - A substantial number of units are expected to be built.
  - Emphasis is placed on low-maintenance cost rather than low-investment cost units.
  - They are operational 24 hours a day for heating and cooling with a fairly large thermal capacity, including hot water supply.
  - They are public facilities requiring comfort and tranquility.
  - Their limited operation budget does not allow employing engineers for maintaining the heating and cooling facilities.
  - Elderly peoples' homes that fulfill these conditions are considered to be prospective targets for the installation of demonstration GHP systems. Subsidizing the cost of installing vertical ground heat exchangers is considered to be an effective promotion activity since it provides the incentive and motivation to introduce the GHP systems in elderly peoples' homes. Such homes should be utilized for demonstration and monitoring purposes. The results should be summarized and published in case study reports.

- **Creating Promotion Centers**

  The widespread installation of GHP systems will be environmentally effective and be helpful in leveling power consumption rates and lowering the heat island phenomenon. From this viewpoint, the Environmental Protection Agency, the Department of Energy, and power companies in the USA are promoting the installation of these systems and created the GHPC (Geothermal Heat Pump Consortium) as a part of joint government/private sector effort.

  The GHP system is applicable to almost all areas of Japan. The fast growth in the number of installed units in Europe and the USA is an excellent encouragement for Japan. A rapid adoption of the system, even faster than in Europe and the USA, can also be expected in Japan by creating adequate GHP promotion centers.

  For 1996, the number of installed GHP systems in the USA was reported to be 50,000. The subsequent yearly growth rate is about 20%. Although the rate is below the target proposed by GHPC, it is still fairly high. However, in Japan the system is not well known by parties that could benefit from it, including consumers, architects, engineers, builders and manufacturers (HPTC, 1998).

  Considering that presently Japan is still in the initial state of GHP system application, it is essential that NEDO should lead promotion and demonstration efforts by creating centers to assist in the introduction of systems suitable for the Japan's conditions. It is essential to study the systems in the USA and Europe very closely, and to determine which is the optimal system for Japan and set target(s) before starting the promotion activities.

- **Subsidy Program**

  When promoting the use of the GHP system, one should stress its economic merits, along with its beneficial effects like energy peak demand reduction and global environmental preservation. The most important point on its economic merits should be that the higher installation costs can be reduced. In this connection, the application of subsidies is considered very important for increasing the system's economic advantages. In view of the present situation of low number of installations in Japan, the application of a subsidy program is expected to have an immediate effect on promoting the introduction of GHP systems and creating an initial demand.

  To help in the creation and design of a subsidy program for the introduction of GHP systems, one could learn from those for solar and wind energy. These types of energies seem to have become economical partly because of the existence of subsidies.

  A possible subsidy program for introducing and increasing the use of GHP systems should include subsidies for:

- Private persons who desire to install the systems in their house,
- Manufacturers, builders and/or dealers who produce, install and sell the systems, and
- Organizations that promote the use of the systems. The funds might be used to cover operational costs, provide infrastructure, prepare manuals, and perform preliminary investigations, including planning.

The subsidy program for private persons would pay for a certain percent of the GHP system installation costs. This would be similar to the program encouraging the introduction of solar energy generation units; it covers the cost **difference with respect to a conventional space heating and cooling system**. In addition, the financial or tax incentive program used to promote wind power projects would also be important.

The subsidy program for manufacturers, builders and/or dealers is expected to be funded by the power companies. It would be similar to the one paying manufacturers 20,000-50,000 yen (US$ 180 - 450) for each kW of the peak shift achievable by the ice-energy storage-type air-conditioning system called "Eco-Ice." The subsidies to manufacturers and builders was offered so that the new technology would be commercially **feasible**, allowing the repair of the facilities as they become old.

Further energy savings could be realized if the electricity for the GHP system compressor could be generated using solar or wind energy, and the Eco-Ice. In this way, the impact of the subsidy program would be further enhanced.

If the economy and performance of the GHP system in Japan could be demonstrated, its use could also be promoted in neighboring Asian countries, as part of the environmental yen loan program being conducted under the Kyoto Protocol adopted at the Third Conference of Parties to the UN Convention on Climate Change (COP3).

CONCLUSIONS

The results of the GHP feasibility study in Japan can be summarized as follows:

- **Present Situation**

Currently the number of GHP systems installed in the USA is about 400,000, and is expected to increase by approximately 50,000 units per year (i.e., about 12% annual growth). In Switzerland, there are about 50,000 systems and the number is growing at an annual rate of 20 % (L. Rybach, pers. comm.). With the more favorable subsurface temperature conditions prevailing in Japan, the introduction of these systems has been found to be feasible. Geothermal heat pump systems **(with vertical and horizontal ground heat exchanger, lake loops, etc.)** are considered to suit the requirements of Japan from both the topographical and environmental points of view.

- **Costs and Widespread Acceptance of GHP Systems**

Studies have shown that if drilling costs for the subsurface heat exchanger can be reduced by an increased number of installed systems, the additional installation costs of a GHP system for an average residential building can be recovered in two years assuming a cost subsidy of 50%, and in 10 years for a 30% subsidy (assuming that the subsidies are available during the initial stages of GHP installation). When the costs are considered over the operating life of the system (typically 24 years), a saving of 2,050,000 - 3,490,000 yen (approx. US$ 19,000 - 32,000) can be achieved with a 30% subsidy.

When the installation of a GHP system in an elderly peoples' home is evaluated, the additional initial costs of the GHP system is recoverable in 9.5 years by applying subsidies currently available (a subsidy of 2/3 of the home construction cost), and recoverable in five years (Table 1) when the subsidy is increased by an additional 7%. When the operating life is extended to 50 years, it can be shown that a project lifetime savings of 0.45 million yen (US$ 4,000) is possible even without subsidies (Table 2).

It can be shown that if all residential buildings in Japan would install a GHP system, a reduction of 52 million tonnes in carbon dioxide emissions could be achieved (a reduction of 4.3 % compared to 1990's emissions; Table 1). In addition, as almost no waste heat is released into the air, these systems are expected to lower heat island effects and reduce peak electric power demands.

- **Technical Tasks**

Although there are no specific technological problems, several aspects of the GHP systems could be improved, including the development of small-scale drilling rigs specially designed for installing GHPs and for drilling into soft and hard rock formations. Also drilling manuals should be prepared, including sections showing the distribution of geologic formation and faults that might affect drilling performance.

- **Tasks to Assist in the Introduction, Promotion and Widespread Acceptance of GHP Systems**

  These tasks include the gathering of geological data, the standardization of systems, the preparation of manuals, the demonstration and monitoring activities, the establishment of a GHP system distribution network, and the creation of a subsidy program. Proposals, relating to GHP systems in Japan, have been based upon examples from Europe and the United States.

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