DEVELOPMENT OF A NEW HEATING AND COOLING SYSTEM WITH THE DOWNHOLE COAXIAL HEAT EXCHANGER (DCHE) AND GROUND - SOURCE HEAT PUMPS

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Summary
One of the most important subjects in the global environment is the relaxation of the global warming. However, the public energy consumption is still increasing and has reached about 30% of the total energy consumption at present in Japan. As a result, the heat island phenomenon in the urban area is rapidly progressing in big cities in Japan including Fukuoka city. One of the main causes is the rapid popularization of the conventional heating and cooling system in houses and buildings. In this paper, we propose a new heating and cooling system of a house with ground-source heat pumps. We have developed a new ground-source heating and cooling system for an experiment house in Fukuoka city. We introduced the Downhole Coaxial Heat Exchanger (DCHE) system to extract heat from the shallow ground. The DCHE system saves electric power and oil consumption, and also does not discharge waste heat to the air. The depth of the necessary well for the heat exchanger was estimated based on the calculation of the thermal load in the experiment house. The heating and cooling system was installed and we started an experiment to verify the high efficiency of the system by continuing the long-term operation. We hope that this system is applied to many houses and contributes to the urban thermal environment.

1. Introduction
The solution of the global warming is that we reduce the use of fossil fuel resources, while we act for the energy saving, and use renewable natural energy which is friendly to the environment. However, the public energy consumption is still increasing and has reached about 30% of the total energy consumption at present in Japan. Therefore, it is very important to convert the energy source for the housing from the conventional to the renewable natural energy utilization. In this paper, we introduce a new heating and cooling system with the ground-source heat pumps for a house. The ground-source heat pumps are rapidly increasing in some European countries and U.S.A. (Lund, 2003) but in Japan we have a small number of installed units because we have different geologic, economic and energy situations etc. from other countries. Then we are trying to develop the high efficiency and cost-effective new heating and cooling system with the ground-source heat pumps.

2. Thermal environment in Fukuoka city and an experiment house
Fukuoka city is located in the south of Japan and it has a high-temperature (The mean and the maximum temperatures in July, 2002 are 27.9 and 36.1 degrees C, respectively) and high-humidity climate in the summer time. The temperature is low (The mean and minimum temperatures in January, 2002 are 7.9 and 0.9 degree C, respectively) in the winter time. Therefore we need both heating and cooling systems in the summer and winter times, respectively. Accordingly traditional heating and cooling systems (air conditioning system in the summer time and oil consumption in the winter time) have been largely

introduced in houses and buildings. As a result, a large amount of electricity is consumed in the summer time and also a large amount of oil is consumed in the winter time.

The conventional heating and cooling systems which consume much more electricity, discharge waste heat to the air, consume oil and discharge CO_2 gas into the air, were popularized rapidly. Therefore it is very important to convert the conventional heating and cooling system to the environment-friendly system. Then we are developing a new heating and cooling system with ground-source heat pumps with which heat is supplied from the shallow geothermal energy, that is, renewable natural energy. This is one of the most important components in developing the Sustainable Habitat System.

A new reclaimed land called "Island City" is now being constructed in the eastern part of Fukuoka city and a big new town will be planned in the near future. In this new reclaimed land, an experiment house with the aim of the environmental adaptation is being constructed and a new heating and cooling system with ground-source heat pump system has been installed in it. This experiment house is made of brick and it is 2-stories standard housing for a family of 4 with the area of about 150 square meters. The investigation of underground structure was carried out in order to clarify thermal characteristics of the underground formation. As a result, it was estimated that the granite with high thermal conductivity exists below 20m depth (Fig.1). We concluded that the experiment site is very suitable to construct the ground-source heat pump system.

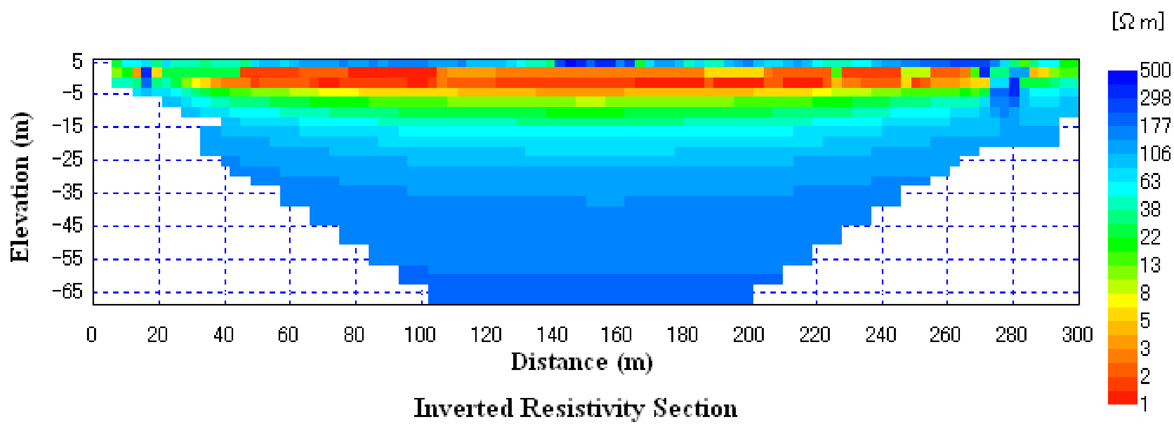

Fig.1 Estimated resistivity structure beneath the experiment house. Higher resistivity values below 20m depth show granitic rocks with higher thermal conductivity.

3. Downhole coaxial heat exchanger system

Horne (1980) has analytically investigated the performance of the coaxial type downhole heat exchanger. Morita et al.(1985) and Morita and Matsubayashi (1986) also confirmed that very efficient heat extraction can be performed with a highly insulated inner pipe and reverse circulation by numerical simulation and named the heat exchanger "Downhole Coaxial Heat Exchanger (DCHE)". The concept of DCHE is shown in Fig.2. This system was originally developed for the deep high-temperature geothermal resources and is also appropriately applicable to the lower temperature geothermal resources as shown in this paper.

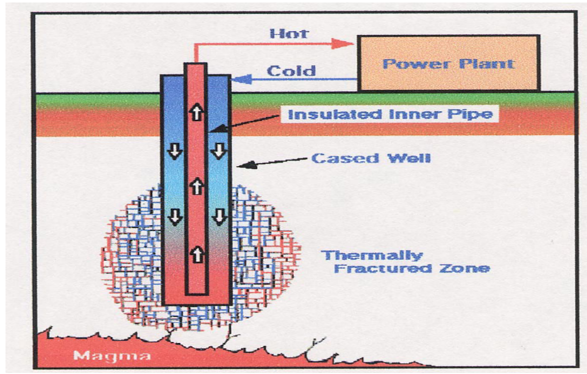

Fig.2 The concept of the Downhole Coaxial Heat Exchanger. This system was originally developed for the deep high temperature geothermal resources.

The Downhole Coaxial Heat Exchanger (DCHE) system was selected to extract heat from the underground for the experiment house. Although the structure of this system is simple, it has high efficiency of thermal extraction and lower electric consumption. The depth of the necessary well for the heat exchanger was estimated based on the calculation of the thermal load of the house. As the result, the well of 60m depth was drilled. The temperature profile of the well is shown in Fig.3. The temperature at the bottom of the well is about 19 degree C which is nearly the same value as estimated before the drilling. After the temperature of the well reached the equilibrium temperature, we did a thermal response test (Measurement of temperature recovery after heating the well to the constant temperature) in order to estimate the effective thermal conductivity of the underground formation and to predict the performance of the system accurately. The effective thermal conductivity of the formation around the DCHE was estimated to be 1.9W/mK. Based on the estimated effective thermal conductivity, we predicted again the performance of the heating and cooling system.

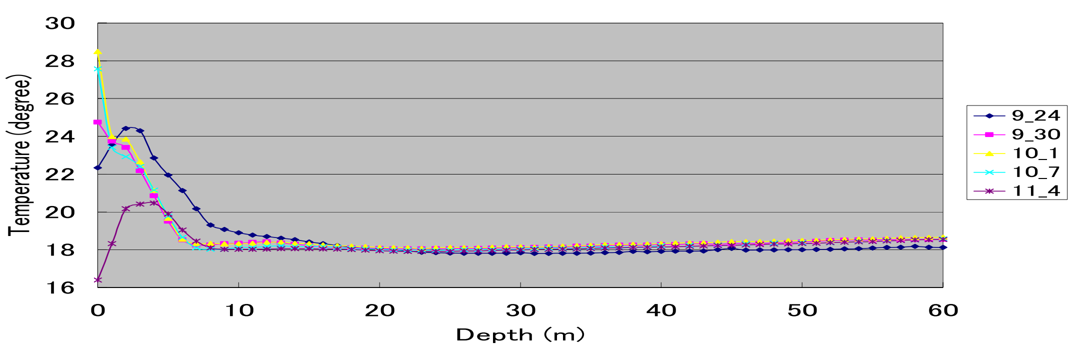

Fig.3 Temperature profiles of the well for heat exchange. Temperatures were measured several times after the drilling ceased on September 16, 2004. The well temperature nearly reached the equilibrium state at the end of September, 2004.

4. Heating and cooling system and estimated performance

The heating and cooling system is very simple and is composed of the DCHE, two heat pumps, a circulation pump and five room air conditioners as shown in Fig.4. A refrigerant is carried directly from the heat pumps to the room air conditioners. The DCHE system is composed of the drill hole (outer tube) and the inner tube whose adiabaticity is very high. In the summer time, the cold heat taken out from the underground is lowered by the heat pumps and it is used for cooling and the warmed waste heat is stored in the underground. On the contrary the cooled waste heat is stored in the underground in the winter time. Therefore waste heat is not discharged into the air.

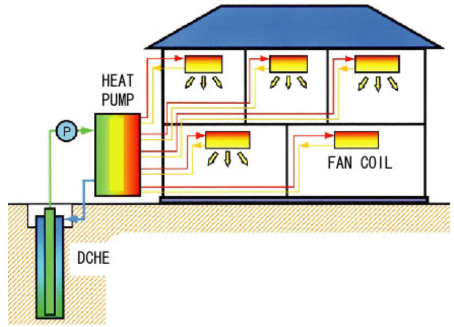

Fig.4 Schematic diagram of the DCHE and the heating and cooling system in the experiment house.

The numerical simulation showed that the high COP (Coefficient of Performance) of near 4.5 for the system was expected. The COP of this system is much higher than that of conventional ground-source heat-pump systems whose COP are about 3. It was also shown that to operate the system through the long term stably is possible. The underground DCHE system was installed in December, 2004. The heat pumps and the room air conditioners are also installed in the house. The experimental operation of the system started in January, 2005. Some experimental results are shown in Fig.5. In February, 2005, we heated the three bedrooms in the night for two weeks. The temperatures in the bedrooms were kept to 22 degrees C. The decline in the formation temperature was small as shown in Fig.5. At present we are trying to verify the predicted high efficiency of the system by continuing the long-term experiment.

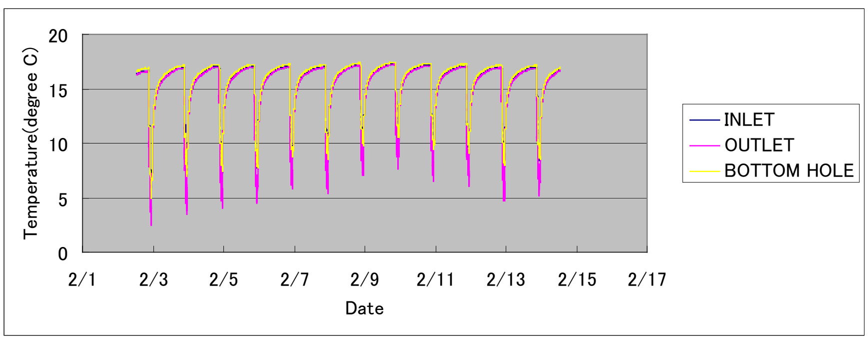

Fig.5 Temperature changes at the inlet to the DCHE, at the outlet from the DCHE and at the bottom hole during the short experiment for heating of the three bedrooms in the night of February, 2005.

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