16. ENERGY PILE SYSTEM IN NEW BUILDING OF SAPPORO CITY UNIVERSITY

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Abstract. Energy Pile System uses building foundation piles as ground heat exchangers. For the new building at Sapporo City University steel foundation pile is decided to be used with the HVAC system. The construction work started in January 2005. Total of 51 steel pipes have been screwed. The paper gives the results from performance analysis and construction phases of the project.

Keywords: Energy Pile System; Ground Heat Exchangers; GSHP

16.1. Use of Building Foundation Piles as Ground Heat Exchangers, "Energy Pile System"

Use of building foundation piles as ground heat exchangers allows great possibility of cost reduction in the construction of ground heat exchangers and attracts a lot of attention in Japan now. This technique has been called as "Energy Pile System" in the European countries. At the same time, it was found the first idea has been already presented in 1964 by Takashi in the journal of Japanese Association of Refrigeration.

Types of foundation piles are classified broadly into three categories. First is the cast-in-place concrete pile. Second is the pre-casting concrete pile, which has a hole in the center. The last one is the steel foundation pile with a blade on the tip of the pile, which is screwed into the ground by a rotating burying machine. The steel foundation pile is able to easily utilize as the ground heat exchanger just after filling water and inserting several sets of U-tubes in the pile. There are two typical methods that enable the steel foundation pile to provide ground heat exchanging. One is direct water circulation method and the other one is indirect method using U-tubes soused in filled water. The latter one can take closed circulating system, which is better in terms of maintenance for many years.

The advantages of the steel foundation pile to be the ground heat exchanger are its high water-tightness and low thermal resistance due to high thermal

H. Ö. Paksoy (ed.), Thermal Energy Storage for Sustainable Energy Consumption, 245–253.

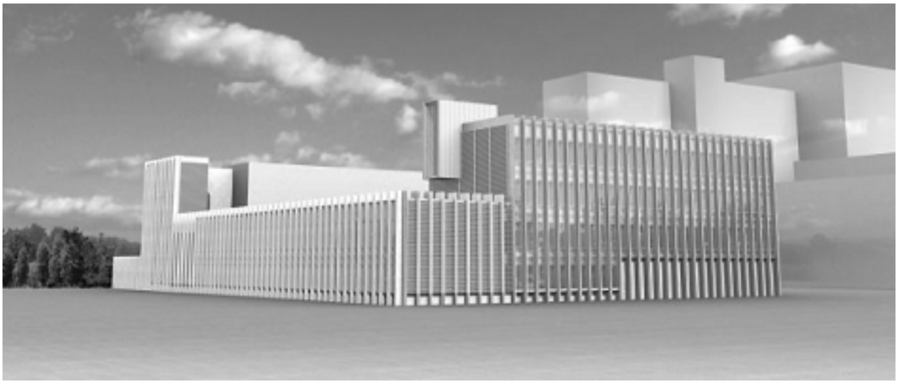


Figure 92. New building of the school of nursing, Sapporo City University (Tentative Name, inaugurated in spring 2006)

conductivity of the steel pile and effect of heat convection of filled water in the pile. In addition to above, huge amount of heat capacity of water in piles expects to play a role of a buffer tank of the heat source system.

16.2. Planning, Designing and Construction of Energy Pile System in Sapporo City University

16.2.1. SAPPORO CITY UNIVERSITY AND ENERGY PILE SYSTEM

Sapporo City University (Tentative Name), which consists from two faculties—the school of design and the school of nursing, will be inaugurated in spring 2006. A new building of the school of nursing shown in Figure 92 is located about 2 km west of the Sapporo central railway station. The mayor claimed to build the environmentally friendly public buildings. After many systems have been examined in this building, Sapporo city council decided to adopt the GSHP system using foundation piles into HVAC system of a new building of the school of nursing in November, 2004. Construction work has started form January 2005. This Energy Pile System will be the world first one which utilizes the steel fundamental piles of the building as ground heat exchangers.

16.2.2. PLANNING OF ENERGY PILE SYSTEM USING BUILDING STEEL FOUNDATION PILES

A new building of the school of nursing consists from two parts. One is a high-rise building for professor's rooms which has 2,800 m^2 of floor area and the other one is a low-rise one for practical training rooms which is 2,000 m^2. Only high-rise one provides steel foundation piles. The layout of steel foundation piles can be realized in Figure 93. 51 piles in all were screwed into the ground under the baseplate at −4.0 m deep from the ground level. The diameter of used steel piles ranges from 600 mmϕ to 800 mmϕ. As shown in Figure 94 hard gravel and pebble layer appears from about 10 m deep in this area. Consequently piles lengths are not so long and their average is 6.2 m. The average effective length for the ground heat exchanger will be 4.7 m long after deducting needed head space of 1.0 m long for footing and the bottom space of 0.5 m long. Total effective heat exchanging length can be 240 m. Total filled water volume is 115 m^3 and its large heat capacity has to be considered in the calculation of dynamic response of this system. The authors had confirmed that heat extracting performance for the indirect heat exchanging method was almost comparable in magnitude to that of direct method when two sets of U-tubes were inserted in a pile in the full scale field experiments. From these reasons, the indirect closed circulating system was adopted and two sets of U-tubes were inserted in to each steel pile.

Hourly heating loads including ventilation load were calculated by using the computational simulation program and then allowable heat supply from Energy Pile System was evaluated by using a GSHP designing tool which the authors have developed under the constrained condition that the minimum thermal medium temperature to the U-tubes in steel foundation piles from the heat pump unit did not drop under −2 °C. Calculation results showed that Energy Pile System can supply daily base heating load of 40 kW. However, as at least heating output of 50 kW is required to claim the subsidy from the Japanese Ministry of the Environment, additional boreholes were planed to be drilled to support remaining 10 kW. Reasonable length for drilling was 75 m deep and it was estimated that three boreholes were needed to satisfy heat output of 10 kW under the same minimum brine temperature condition. Anyhow heating output of 50 kW supplied from the GSHP was only a fraction of building heating load. Eventually, heat from the GSHP was decided to apply to heating and cooling the outside fresh air in the ventilation unit because it requires relative low temperature for heating and natural cooling is possible during summer. Recovered heat by natural cooling is released into the ground for recharging heat capacity of the soil.

16.2.3. DESIGNING TOOL

The layout of building foundation piles always depends on the building structure, geological condition and the type of foundation piles. It is not in regular lattice pattern in most cases. Many existing designing soft wares utilize so-called "G-function" and they cannot support the irregular layout. The author's

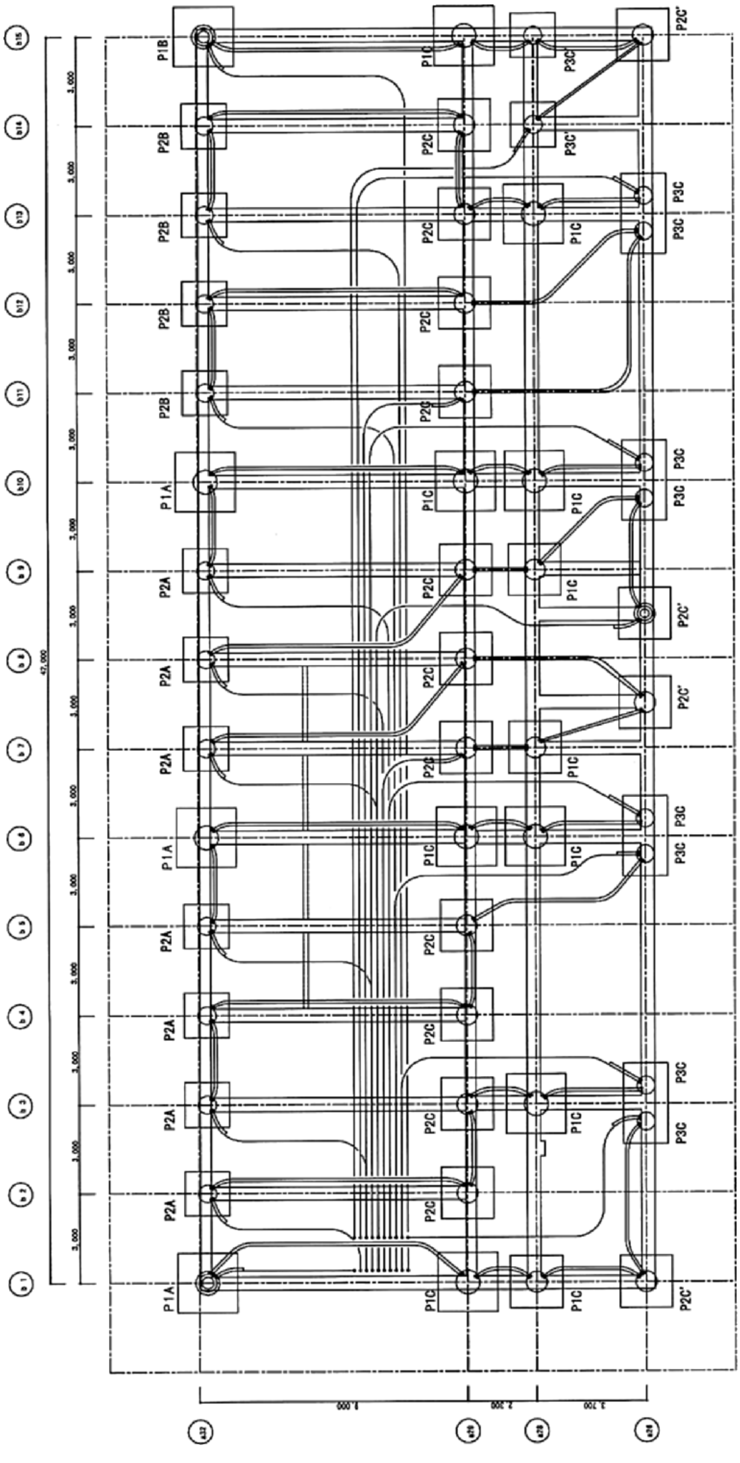


Figure 93. Layout of installed steel foundation piles and piping (51 piles with 600 ~ 800 mm ϕ in diameter)

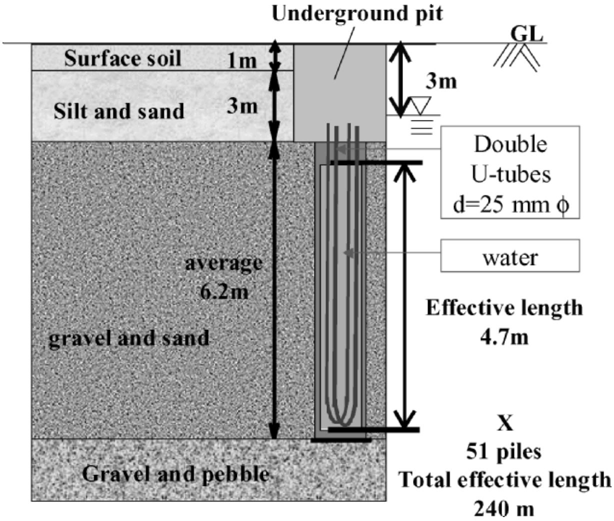


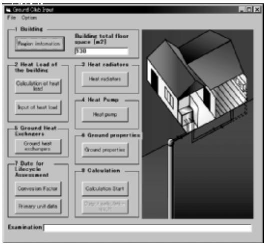
Figure 94. Geological condition and details of underground construction

group has developed a novel GSHP designing and performance prediction tool which is able to treat the random layout of ground heat exchangers with high speed calculation algorithm. Other features of this tool are that it can treat the effect of huge heat capacity in the ground heat exchanger and the thermal response of a short ground heat exchanger with a big diameter is calculated using cylindrical heat source theory modified by the similar method which Eskilson presented. Convolution integral is carried out according to the hourly heating and cooling loads. In addition, this tool includes database of heat pump performance curves according to both outlet temperature of the primary side and inlet temperature of the secondary side, energy prices and specific CO_2 emissions. Consequently, this tool can calculate hourly energy consumption and energy cost. Then life cycle energy and life cycle CO_2 emissions are evaluated. Graphical input screens and also visually output screens provide the user-friendly interface as shown in Figure 95. Particularly, it takes only for a few minutes to get results of multiple ground heat exchangers for two years.

16.2.4. PREDICTION OF PERFORMANCE

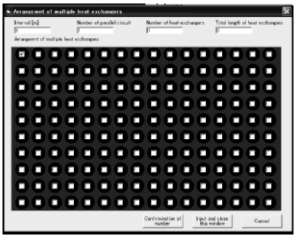
Before the calculation of performances, heating and cooling loads which can be covered by the Energy Pipe System are evaluated. Total amount of heating and cooling is 230 GJ and 75.6 GJ, respectively, and peak loads are 50 kW for heating. On the other hands, average effective thermal conductivity was measured by the on-site thermal response test and it was 2.2 W/(mK).

1. User friendly data input procedure and graphical output



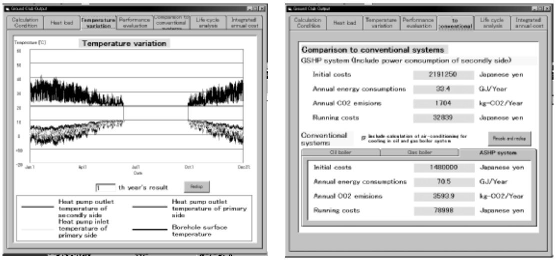
Building total floor space [m2]: 138

2. High speed algorithm for calculation of multiple ground heat exchangers



GHEX Layout input window

3. Short calculation time according to hourly H&C loads for 2-10 years (1 minute for 2 years calculation)



Comparison to conventional systems

GSHP system (Include power concumption of secondly side)

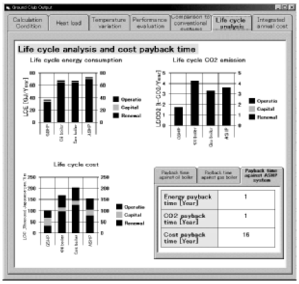
Initial costs	2191250	Japanese yen
Annual energy consumptions	33.4	GJ/Year
Annual CO2 emisions	1704	kg-CO2/Year
Running costs	32839	Japanese yen

Conventional systems ☑ Include calculation of air-conditioning for cooling in oil and gas boiler system

ASHP system

Initial costs	1480000	Japanese yen
Annual energy consumptions	70.5	GJ/Year
Annual CO2 emisions	3593.9	kg-CO2/Year
Running costs	78998	Japanese yen

4. Evaluation of CO2 emissions, costs and lifetimes for LCA



Energy payback time [Year]	1
CO2 payback time [Year]	1
Cost payback time [Year]	16

Figure 95. User-friendly interfaces for input and output of a developed design tool

The minimum brine outlet temperature is −0.8 °C during the fifth year's operation. During summer the outside air for the ventilation is cooled by the circulated brine between ventilation units and U-tubes in foundation piles and then removed heat is released into the ground. Finally it is realized that brine temperature after the summer season completely recovered to the initial temperature at the start of the fifth year's operation. This means that sustainable operation can be kept in this Energy Pile System.

Table 16 describes the predicted performance of the GSHP system. Total amount of extracted heat from the ground reaches 180 GJ and electricity consumption is 13.9 MWh. In this time COP of the heat pump unit is 4.4. When this system will adopt a constant—speed pump which can cover the maximum heat output, SCOP is 2.7. This result suggests that a variable speed pump according to the heat loads is effective to improve SCOP. On the other hand, released heat into the ground during summer is 56 GJ and the electricity of 3.6 MWh is consumed to circulate the brine between U-tubes in the foundation piles and ventilation units. SCOP during summer is estimated to be 5.7. This can be also improved.

TABLE 16. Predicted annual performance of the GSHP system

Amount of heat extraction	Electric power consumption	Electric power consumption of the circulation pump	Average COP	Average SCOP
Heating period				
180.2	13,886	7,155	4.4	2.7
Amount of heat injection to the ground (GJ)	Electric power consumption	Electric power consumption of the circulation pump	Average COP	Average SCOP
Cooling period				
75.6	0	3,689	—	5.7

Comparisons of annual CO_2 emission and annual operating cost of the GSHP system with those of gas systems which are a gas boiler without a chiller and a gas cooling and heating machine are shown in Figure 96. Annual operating cost of GSHP is 3,500 USD and it is only a half of a gas boiler system and 42% of a gas cooling and heating system. Annual CO_2 emission of GSHP is 12 tons. This is 3.8 tons and 7.4 tons smaller than gas systems, respectively.

16.3. Process of Construction

Pit excavation work of this building has started in January 2005. Totally 51 steel piles were screwed by using rotating burying machine from February 2005 indicated in Figure 97. After all piles were installed, internal spaces were filled up by tap water and two sets of U-tubes were inserted as shown in Figure 98. Figure 99 shows how U-tubes come outside through the reinforced frame of footings. U-tubes were protected by sheathed plastic tubes.

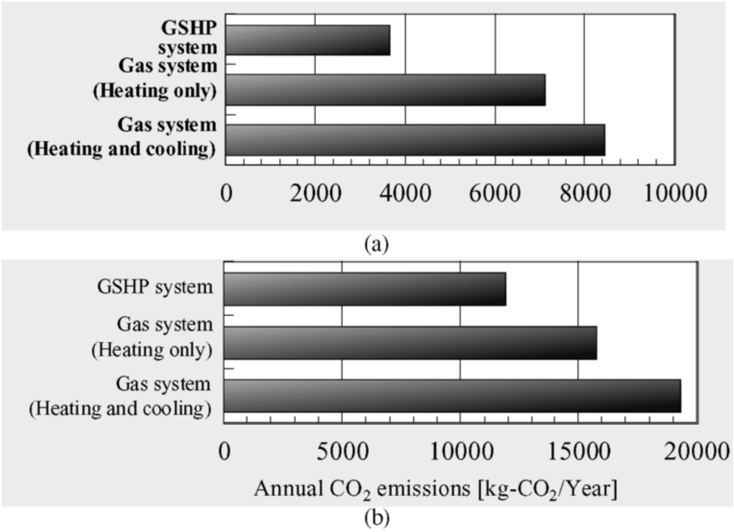


Figure 96. Comparisons of annual CO_2 emission and annual operating cost of the GSHP (a) Comparisons of annual operating cost of the GSHP (b) Comparisons of annual CO_2 emission

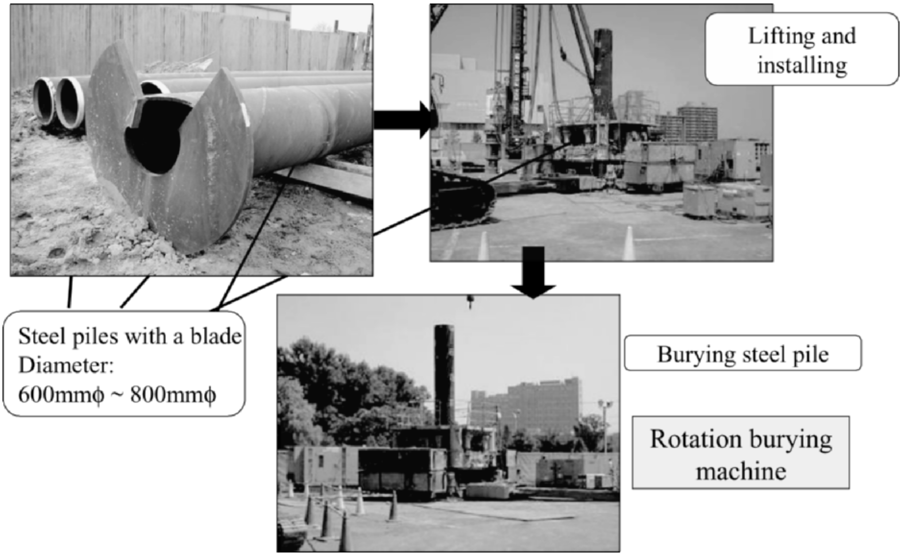
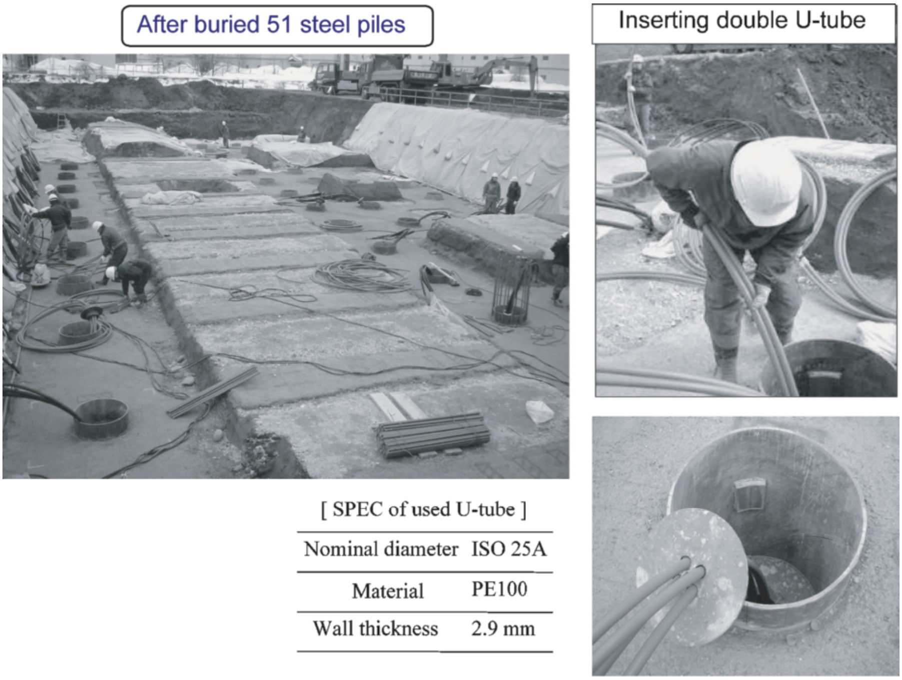


Figure 97. Steel piles with a blade on the tip and a rotation burying machine



[SPEC of used U-tube]

Nominal diameter	ISO 25A
Material	PE100
Wall thickness	2.9 mm

Figure 98. Layout of installed 51 steel foundation piles and inserting of two sets of U-tubes

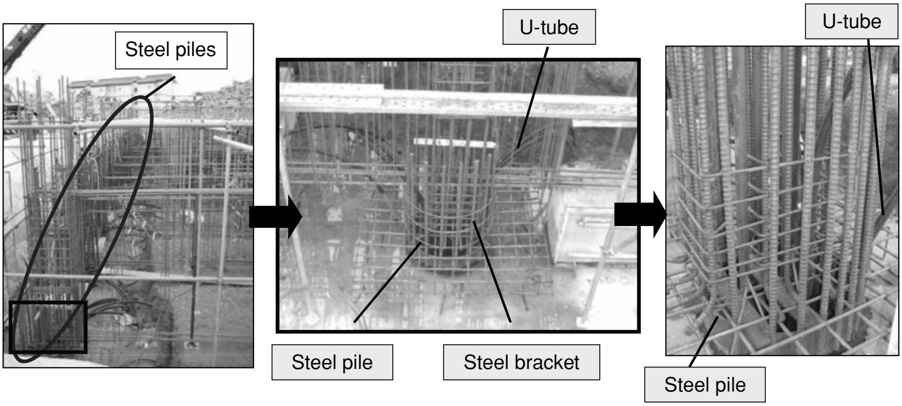


Figure 99. U-tubes come outside through the reinforced frame of footings