Heat Loss from Hot Water Floor Heating System to Crawl Space:  
Field Survey and Improvement of Energy Consumption

Hisashi Miura*, Shuichi Hokoi, Nobuo Nakahara and Huang Yinong

1 Graduate Student, Graduate School of Engineering, Kyoto University, Japan  
2 Professor, Graduate School of Engineering, Kyoto University, Japan  
3 Nakahara Laboratory, Environmental Syst-Tech. (NESTEC), Japan

Abstract
In order to improve the performance of the floor heating system, it is very important to investigate how the heat loss is caused and how the energy consumption of the system could be reduced. Therefore, the heat loss from a hot water floor heating system was investigated in a residential house in Japan. Through the investigation process, several improvements were made in the heating system. To know the effect of the improvements, the upward/downward heat flows from the hot-water panel and the heat loss from the piping of the floor heating system were calculated. In result, insulating the piping and attaching the insulation below the floor improved the upward heat flow rate from the panel. However closing the ventilation openings hardly improved the rate of the upward heat flow from the panel. Although insulating the pipe and attaching the insulation below the floor improved the upward heat flow, heat loss from the piping was still high. To reduce the heat loss from the floor heating system, it is much effective to insulate the piping, compared with the improvement of the insulation and structure of the floor.

Keywords: floor heating; insulation of piping; energy consumption; crawl space

1. Introduction
Recently, architectural technology has advanced remarkably and many kinds of heating/cooling systems have been developed. Floor heating system is one of them. Floor heating systems can provide high amenity environment in rooms because the vertical air temperature difference is small and the dust is not scattered (compared with a convection heating), among other advantages. Therefore, the floor heating systems have been becoming popular in Japanese residential houses.

There is a substantial volume of work regarding floor heating system. Watanabe (2001) gives a general overview of the study in Japan on the thermal comfort zone, which is the combination of air temperature and surface temperature. Concerning operation of the system, there are many researches such as comparison between continuous/intermittent operation modes and conventional on-off control (Cho, 1999), and a predictive control (Lee, 2002). However, most of these studies aim at the floor heating system whose pipe is embedded in concrete. There is few works on the floor heating system installed in a house with crawl space like in Japan. Shimizu (1999) produced an experimental device in order to investigate the thermal output from a floor heating system. Inoue et al. (1997) discuss simplified estimation methods of heat output in hot water floor heating systems. But the energy consumption of the floor heating system in residential house, where people are living, has not been reported so much. To reduce the heat loss and the energy consumption of the system, it is very important to know the realized situation and investigate how the efficiency of the system could be improved.

The purpose of this paper is to investigate the actual situation of the heat loss from a hot water floor heating system to a crawl space. Through the investigation process, several improvements were made in the heating system. Based on these results, we investigated how we can achieve a higher efficiency of the system.

*Contact Author: Hisashi Miura, Graduate Student, Graduate School of Eng., Kyoto University, Yoshida-honmachi, Sakyo-ku, Kyoto-city, Kyoto, 606-8501 Japan  
Tel: +81-(0)75-753-5779 Fax: +81-(0)75-753-5779  
e-mail: hisashi@archi.kyoto-u.ac.jp  
(Received November 8, 2002 ; accepted March 3, 2003 )
2. Measurement
2.1 Outline of Surveyed House

The residential house where the measurements were carried out is a steel-frame house in Nishinomiya, between Kobe and Osaka, Japan. An elderly lady was living in the house and she spent most of her time in the bedroom. Figures 1 and 2 show the first and second floor plans.

![Fig. 1. First Floor Plan](image1)

![Fig. 2. Second Floor Plan](image2)

2.2 Air Conditioning System

A central air conditioning system is installed in this house. It supplies and exhausts the minimum necessary air volume (200 m$^3$/h for the whole house) through a total heat exchanger (Fig. 3). During heating and cooling seasons, the hot/chilled water produced by a heat pump is supplied to the fan coil units. The piping for heating and cooling runs through the crawl space, goes upstairs, and is then connected to the fan coil units in the duct space (Fig. 4).

![Fig. 3. Duct and Air Conditioning Systems](image3)

![Fig. 4. Piping of Air Conditioning System](image4)

2.3 Hot Water Floor Heating System

Hot water floor heating system is also equipped. Figure 5 schematically shows the hot-water panels and piping network of the floor heating system. Hot water is produced by a gas-boiler and flows to the header located in the crawl space beneath the closet-corridor. The header controls the flow rate. Figure 6 shows a typical longitudinal section of the piping. As can be seen in the figure, the surface of the piping is uneven and the air between convex concavities reduces the heat loss from the piping. Figure 7 shows the structure of the floor. The hot-water panel is set on the joist, and the felt is used as the substrate of the carpet. Polystyrene foam was attached in February 2001, in order to reduce the downward heat flow from the panel.

![Fig. 5. Hot Water Panel and Piping Network for Hot Water Floor Heating](image5)
2.4 Crawl Space

Figure 8 shows the crawl space. The pipe suspended from the sleeper is a part of the heating and cooling piping system to the fan coil units. The pipe lying on the ground is part of the hot water floor heating system. The polystyrene foam insulation attached in February 2000 can be also seen.

2.5 Improvements on Hot Water Floor Heating System

Through the investigation process, the following improvements were made (Fig. 9).

1) Insulation of Piping
   To reduce the heat loss of the piping, polystyrene foam (12mm) was wound around the pipe in February 2000.

2) Attachment of Insulation below Floor
   To reduce the downward heat flow from the hot-water panel, polystyrene foam was attached below the floor in February 2001 (Fig. 7). The present insulation of the floor is 145mm thick (glass wool 85mm and polystyrene foam 60 mm).

3) Closing of Ventilation Openings
   To reduce the heat loss from the crawl space to the outside through the ventilation openings, these were closed with polystyrene foam in March 2001. If the heat loss decreases, the temperature of the crawl space would rise, and then the heat flow from the piping and the panel to the crawl space would decrease. Therefore closing the ventilation openings is expected to reduce the heat loss from the floor heating system.

2.6 Procedures of Measurement

The period of the measurement is shown in figure 9. To calculate the heat loss and heating load of the house, the temperatures, solar radiation, electricity/gas consumptions, supply/return water temperatures and mass flow rate of the heat pump were measured in winter 2000 (1/27-30 and 2/24-27). The surface and air temperatures were measured both in the bedroom and in the crawl space below the bedroom in 2000 (1/23, 1/30, 2/15 and 2/22) and 2001 (1/26 - 4/22). Then the water temperatures and mass flow rate of the floor heating piping system were measured in 2000 (1/23, 1/30, 2/15 and 2/22) but not in 2001 (1/26 - 4/22). Figure 10 shows the temperature measurement points. During the periods, the outdoor air temperature was also measured.
3. Calculation of Heat Loss from Floor Heating

To investigate the heat load of the house, the heat balance is simulated (Hokoi et al. 2002). Then to investigate how to improve the whole system, the heat loss from the piping and the upward/downward heat flows from the panel are calculated. Details are explained below.

3.1 Heat Loss and Heat Load of House

Using the data obtained in February 2000, the heat loss and heat load were estimated. Heat transmission through walls, windows, floors and the roof were calculated multiplying the difference between the indoor and outdoor air temperature by the respective thermal transmittance. The heat supplied by the gas boiler and the heat pump was calculated reading the gas and electricity consumption meter. Heat loss from the piping was calculated by multiplying the temperature difference between the water and the crawl space by the thermal transmittance of the pipe. When the water temperature in the piping of the floor heating system was not measured, it was assumed as at 70.0 °C. The upward and downward heat flows from the panel were calculated by dividing the total heat from the panel in inverse proportion to the upward and downward thermal resistance.

3.2 Heat Loss from Piping and Upward/Downward Heat Flows from Panel

To calculate the heat flow from the hot-water panel, a numerical simulation program of the panel using the finite difference method was developed. Input data to the simulation program is the water inlet temperature, the mass flow rate of the hot water, air temperature in the bedroom and the crawl space (Fig. 11). Thermal conductivity and specific heat of the floor materials and the heat transfer coefficient are determined so that the calculated surface temperatures agree with the measured values (Fig. 12). Table 1 shows the thermal conductivity, specific heat and the heat transfer coefficient.

The heat loss from the floor heating piping system is given by,

\[ H = C_w u (T_a - T_b - T_c + T_d) \]  

where,

- \( H \) = heat loss from piping per day;  
- \( C_w \) = specific heat of water;  
- \( u \) = mass flow rate of water per day;  
- \( T_a \) = inlet water temperature;  
- \( T_b \) = outlet water temperature;  
- \( T_c \) = inflow water temperature to header;  
- \( T_d \) = outflow water temperature from header. \( T_a, T_b, T_c \) and \( T_d \) refer to average daily temperatures.

The thermal transmittance of the pipe was calculated by,

\[ K = \frac{Q}{(T_{water} - T_{crawl})} \]
where, 
$K =$ thermal transmittance of pipe; $Q =$ heat loss from pipe per meter; $T_{\text{water}} =$ water temperature; and $T_{\text{crawl}} =$ crawl space temperature.

The thermal transmittance thus calculated was 0.388 (W/mK) before insulating the piping and 0.254 (W/mK) after insulation. When the water temperature in the piping of the floor heating system could not be measured, the thermal transmittance of the piping was calculated by multiplying the difference between the water and the crawl space temperatures by the respective thermal transmittance.

4. Results

4.1 Energy Consumption

The monthly electricity and gas consumptions in 1998 are shown in Figure 13, along with the total cost. Electricity and gas consumptions during winter were quite large when the floor heating and the air conditioning system are operating.

4.2 Heat Loss and Heat Load

In order to understand why consumption of both electricity and gas during winter was large, both the heat loss and the heat load were calculated by using the data obtained in winter 2000 (Fig. 14).

As expected, the heat loss from the piping of both the air conditioning and the floor heating systems was significant. Energy supplied by the gas boiler and the heat pump was 434 MJ/day (gas boiler: 243 MJ/day, heat pump: 191 MJ/day). Heat loss was 190 MJ/day (from the piping of the floor heating system: 115 MJ/day, from the panel: 20 MJ/day, from the piping of heat pump: 55 MJ/day), which corresponds to 44% of the total energy supply.

4.3 Temperature around Crawl Space

The temperatures around the crawl space in February 2001 are shown in figure 15. Although the ventilation openings were not closed, the temperatures of the crawl space are much higher than the outdoor air temperature.

The temperatures of the crawl space under kitchen, dining and corridor where the piping of the floor heating system runs, were high.

The air temperature, the surface temperature of the pipe and the ground surface temperature in the crawl space under the bedroom in winter (February 2001) are shown in figure 16. The surface temperature of the piping of the floor heating system was 7 degrees higher than the air temperature. The lower (back) surface temperature of the floor and the surface temperature of the piping of the air conditioning system were 3 degrees higher than the air temperature.
4.4 Temperature of Crawl Space (after ventilation openings are closed)

The correlation between the outdoor temperature and the crawl space air temperature under the bedroom (2/1 - 4/8) is shown in figure 17. Even before closing the ventilation openings, there is almost no correlation. From March 19, the ventilation openings were kept closed. After the closing, the temperature of the crawl space is hardly influenced by the outdoor air temperature, and the mean temperature of the crawl space rose by about 3 degrees.

![Fig. 17. Correlation between Outdoor Temperature and Crawl Space Air Temperature under Bedroom (2/1 - 4/8)](image)

4.5 Upward/downward Heat Flows from Hot-Water Panel and Heat Loss of the Piping

The upward/downward heat flows from the hot-water panel and the heat loss from the piping of the floor heating system were calculated. Table 2 shows outdoor air temperature, the temperatures in the bedroom and the crawl space. Figure 18 shows the upward/downward heat flows from the panel and the heat loss of the piping, and figure 19 shows their percentage.

Before the improvements, the upward heat flow rate was very low, 43.0 %, while the heat loss from the piping was high, 39.3 %. After the pipe was insulated, the heat loss from the piping decreased from 39.3 % to 28.8 %. When the polystyrene foam was attached below the floor, the downward heat flow decreased from 20.4 % to 14.4 %. The closing of the ventilation openings was not followed by a remarkable change in the heat flow.

Finally, the upward heat flow was improved up to 55.7 %, and the ratio of the upward heat flow to the downward heat flow was 4 to 1. However the heat loss rate of the piping was still high, 31.1 %.

| Temperature | Outdoor (°C) | in the Bedroom (°C) | in the Crawl Space (°C) |
|-------------|-------------|---------------------|------------------------|
| Before improvement | 6.0 | 21.5 | 18.0 |
| After piping was insulated | 5.0 | 17.7 | 14.4 |
| After polystyrene foam was attached | 5.2 | 22.1 | 16.3 |
| After ventilating openings were closed | 8.6 | 24.1 | 20.6 |

![Fig. 18. Upward/Downward Heat Flows from Panel and Heat Loss from Piping of Floor Heating System](image)

5. Possible Improvement of System Efficiency

Through the investigation process, several improvements were made in the heating system. After evaluating the data obtained, we estimated how a higher efficiency of the system could be achieved (Fig.19). However these calculations were made in different conditions, namely the crawl space and bedroom had different air temperatures in each case (table 2).

Therefore, in order to compare the effect of each improvement under the same conditions, calculation was made assuming the following three situations: a) the temperature of the bedroom is the same, 23.0 °C, b) the water inlet temperature is the same, 70.0 °C, and c) the water mass flow rate is the same. Finally, the following measures were examined in order to understand how a
higher efficiency of the system could be achieved. Namely:

a) the temperature of the crawl space was set at 14, 15, 16, 17 and 18 °C respectively, to estimate the influence of the crawl space temperature,

b) the joist and sleeper were removed to decrease the downward heat flow from the panel (heat bridges),
c) the felt which is used as the substrate of the carpet was removed to increase the upward heat flow from the panel.

Figure 20 shows the result. Due to the improvements, the upward heat flow increased and the downward heat flow decreased. The crawl space temperature had very little influence on the upward and downward heat flows, and the heat loss from the piping.

6. Discussion

The monthly electricity and gas consumption in 1998 is shown in Figure 13. The consumptions of both electricity and gas during winter are quite large.

In order to understand the situation, the heat loss and the heat load were calculated (Fig. 14). The heat loss from the piping of both the air conditioning system and the floor heating system is significant. It is evident that the heat loss of the piping led to a significant waste of electricity and gas.

The crawl space temperature during February 2001 is shown in figure 15. The temperatures of the crawl space under the kitchen, dining and corridor are high. This is also due to a large heat loss from the piping running in these crawl spaces.

The temperatures in the crawl space under the bedroom in winter (February 2001) are shown in figure 16. The surface temperature of the piping of the floor heating system, the lower (back) surface temperature of the floor and the surface temperature of the piping of the air conditioning system are very high. These indicate that the heat loss of the piping and the downward heat flow from the panel are quite large.

It can be concluded that the heat loss from the piping caused a waste of energy. In order to know how the situation could be improved, the heat loss of the piping, upward/downward heat flows from the hot-water panel and the heat loss from the piping of the floor heating system were calculated (figs. 18 and 19). Insulating the piping and attaching the insulation below the floor improved the upward heat flow rate from the panel. However closing the ventilation openings hardly improved the rate of the upward heat flow from the panel. This is because the rise of the crawl space temperature is much smaller than the difference between the water temperature and the crawl space temperature. However, the rise of the crawl space temperature may reduce the heat transmission through the floor of the rooms, especially the rooms where the floor heating system is not installed such as the Japanese style room, corridor, storage and so on. Therefore, the influence of closing the ventilation openings must be evaluated in terms of the total heat loss in the house.

Although the ratio of the upward to downward heat flow was improved to 4:1, the heat loss from the piping is still high, 31.1 %. To reduce the consumption of the floor heating system, the heat loss from the piping must be further reduced.

After evaluating the results obtained, we analyzed how a higher efficiency of the system could be achieved. To compare the effect of each improvement under the same conditions, the calculation was carried out assuming the several situations. Figure 20 shows the result. The heat loss from the piping decreased significantly after the pipe was insulated. To reduce the heat loss from the floor heating system, it is much effective to insulate the piping, compared with the improvement of the insulation and structure of the floor.

7. Conclusion

The heat loss from a hot water floor heating system to a crawl space was investigated. The measurements were carried out in a residential house in Nisinomiya, in Japan. Main results are as follows.

1) The monthly electricity and gas consumptions were surveyed. The consumption during winter was very large.

2) The heat loss and the heat load were calculated based on the measured results. The heat loss from the piping of both the air conditioning system and the floor heating system was significant.

3) The temperatures of the crawl space were high and the surface temperatures of the piping also were very high.

4) The upward/downward heat flows from the hot-water panel and the heat loss from the piping of the floor heating system were calculated. Although insulating the pipe and attaching the insulation below the floor improved the upward heat flow, heat loss from the piping was still high. The heat loss of the piping must be further reduced.
5) After evaluating the results obtained, we analyzed how a higher efficiency of the system could be achieved. The insulation of the pipe can reduce the heat loss from the system significantly, compared with closing the ventilation openings and removing the joist, sleeper and felt.

Acknowledgments
Many thanks are given to house maker, equipment and systems, and Energy Company. We are also deeply indebted to the resident for her hearty cooperation; nevertheless she was not always in good health.

References
1) Cho, S.-H. and Zaheer-uddin, M. (1999) An Experimental Study of Multiple Parameter Switching Control. Energy, Vol.24, No.5, 433-444.
2) Hokoi, S., Maeda, M., Nakahara, N. and Iwamae, A. (2000) Field Survey on Thermal Environment and Energy Consumption in Well-Insulated and Air-Tightened Residential House in Kansai District, Japan. Proceedings of Healthy Buildings 2000, Espoo, Finland, Vol.2, 587-592.
3) Inoue, U., Ishino, H. and Kohri, K. (1997) Journal of Architecture, Planning and Environmental Engineering, No.494, 23-28.
4) Lee, J.-Y., Yeo, M.-S. and Kim, K.-W. (2002) Predictive Control of the Radiant Floor Heating System in Apartment Buildings. Journal of Asian Architecture and Building Engineering, 1 (1), 105-112
5) Shimizu, N. (1999) Study on Thermal Output of Floor Heating System. Journal of Architecture, Planning and Environmental Engineering, No.516, 61-68.
6) Watanabe, S. (2001) A Review of Floor Heating Research in Japan. Journal of the Human-Environmental System, Vol.5, No.1, 13-23.