Development to improve energy efficiency of floor heating systems with thermal comfort

D. Ito, Y. Kawahara, Y. Maruyama, and M. Morioki
TOHO GAS CO., LTD. 19-18 Sakurada-cho, Atsuta-ku, Nagoya City, Aichi Pref. 456-8511, Japan

Abstract

Gas hot water floor heating systems are highly appreciated for their features such as creating a comfortable thermal environment to keep the head cool and the feet warm and they are being installed increasingly, mainly in new residences, in recent years. Despite the high comfort level, this type of heating system is required higher level of energy efficiency by Japanese energy conservation standards.

This paper describes the technical development to raise the energy efficiency of floor heating systems to meet the above-mentioned standards. At the same time, we also focus on the energy saving effects caused by the thermal comfort of floor heating systems.

We aimed to increase the efficiency of the burner by connecting the floor radiant panels of two separate rooms in series to increase heat release and enlarge the temperature difference between supply and return fluid. Also, by installing vacuum insulating material on the underside of the floor radiant panels, we aimed to increase the indoor heat release rate. In addition, by combining the gas cogeneration and the ganged control system of the room air conditioner and the floor heating, we were able to power the air conditioner with electricity generated by the cogeneration, and use the exhaust heat of the power generation to warm up water for the floor heating. In this way, we aimed to reduce the amount of energy lost.

We also introduce that when using floor heating, because the whole body is warmed from the feet up by radiation and conduction of heat from the floor surface, the necessary room air temperature to achieve an equivalent level of thermal comfort can be set at approximately 2˚C less than when using room air conditioner [1].

1. Introduction

Gas hot water floor heating systems are highly regarded because of their ability to create a comfortable thermal environment to keep the head cool and the feet warm. In recent years, the number of installations in Japan has increased, particularly in newly built housing.

The basic structure of the gas hot water floor heating systems is a hydronic system, as shown in Figure 1. Water is heated by a gas hot water heater and pumped through plastic tubing, using the pump inside the heater, to the floor radiant panels. Then, after its heat is released, the water returns to the heater through a different set of tubing. The floor heating controller for the room is connected to the heater through signal wires. Using this controller, the user can cause hot water to be generated at the heater and pumped to the under floor radiant panels. The internal structure of the floor radiant panels consists of plastic hot water tubing running through expanded polystyrene foam panels. These panels are incorporated into the framework of the building. For example in the construction of a new detached house, as shown in Figure 2, the panels are installed between the plywood substrate that covers the underfloor thermal insulating material and the floor finishing materials, such as tatami mats or wooden floor boards, that make up the surface of the floor. In other words, the gas hot water floor heating system heats the interior of the room using the heat of water that has been heated by the water heater and pumped to the floor radiant panels. The heat then radiates upward from the panels through the surface of the floor. This system allows the creation of a comfortable thermal environment to keep the head cool and the feet warm.

However, while floor heating systems may be comfortable, this type of heating system is required higher level of energy efficiency by Japanese energy conservation standards. In this paper, we introduce some attempts to raise the energy efficiency of floor heating systems to meet the above-mentioned standards. Firstly, we will look at technical developments that aim is "system component performance enhancement". Specifically, we will introduce methods of "increasing the efficiency of the burner to heat the water" and of "increasing the indoor heat release rate of floor radiant panels". Secondly, we will look at technical development of an operational model to achieve "system-wide improvement of home heating efficiency". Finally, we will also look at "the energy saving effects caused by the thermal comfort of floor heating systems".

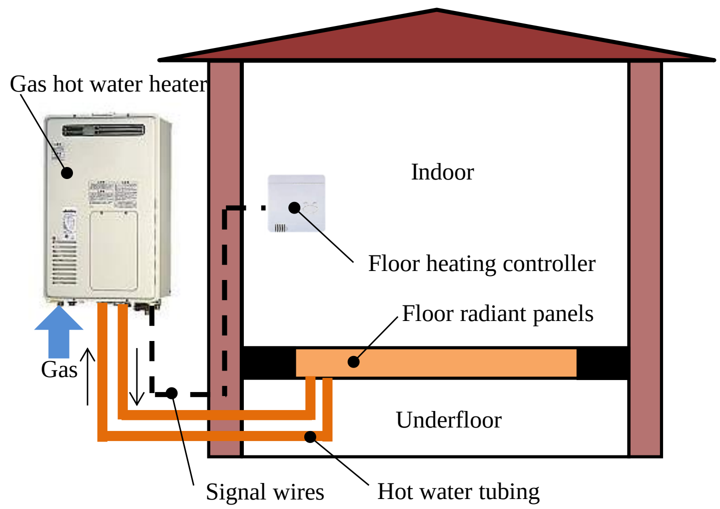


Fig.1 Basic Structure of Gas Hot Water Floor Heating Systems

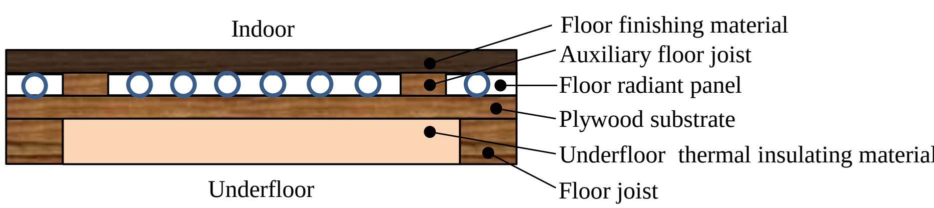


Fig.2 Example of Floor Radiant Panel Installed in New Detached Houses

2. System component performance enhancement

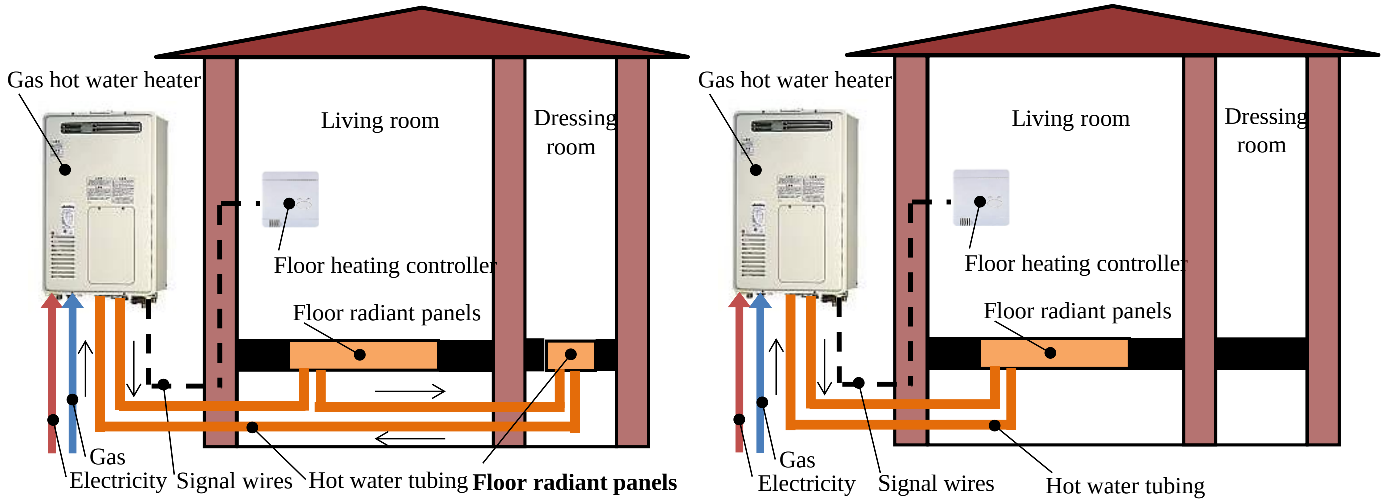
2.1 Increasing efficiency of burner to heat water

The performance of burners in the water heaters tends to increase when the temperature difference between supply and return fluid becomes larger. Based on this tendency, we attempted to improve burner performance by connecting the floor radiant panels of two separate rooms in series to increase heat release and enlarge the temperature difference between supply and return fluid.

In our evaluation as shown in Figure 3, we installed two types of floor heating systems in a test house inside an artificial indoor climate chamber. We measured the volume of gas and electricity consumed by the heater, and the floor surface temperature and air temperature inside the room, for each system. For the trial system, we connected the floor radiant panels in two different rooms in series, with the upstream panels installed in the living room and the downstream panels in the dressing room. That is, the system was set up so that the floor heating in the dressing room uses the residual heat of the water returning to the heater from the floor radiant panels in the living room. By comparison, in the conventional system, floor radiant panels were only installed in the living room.

The main test conditions were as shown in Table 1. To simulate the temperature conditions of a detached house in winter, the outdoor air temperature was set at 5˚C and the initial room air temperature at approximately 15˚C. The floor heating controller for the living room was set to the equivalent of 20˚C. Based on the Japanese energy conservation standards for the heat loss coefficient of new detached houses in a metropolitan area of 2.7W/m^2 K, the test house was constructed with a heat loss coefficient equivalent to this standard value. The floor area of the rooms was equivalent to that generally found in new detached houses in Japan. The area of the living room was approximately 26m^2 and the dressing room approximately 3m^2. The operating time for each system was seven hours, based on the actual length of time that heating is used in residential households.

The result of the above measurements, as shown in Figure 4, is that we confirmed that the trial system achieves a reduction in primary energy consumption of approximately 9% compared to conventional systems.



(a) Trial System (b) Conventional System

Fig.3 Comparison of Test Systems

Table 1 Test Conditions

Condition	Specified Value
Outdoor air temperature	5˚C
Initial room air temperature	Approx. 15˚C
Heater setting in living room	Equivalent to 20˚C
Heat loss coefficient of test house	Equivalent to 2.7 W/m^2 K
Living room floor area	Approx. 26 m^2
Dressing room floor area	Approx. 3 m^2
System operation time	7 hours

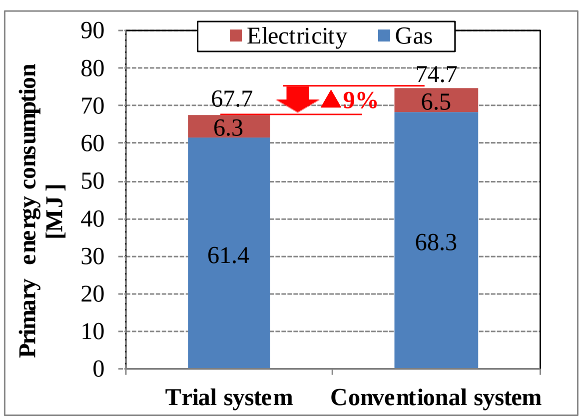


Fig.4 Primary Energy Consumption

However, in the trial system, a reduction in the circulation flow of hot water was observed as a result of the increased pressure loss, with the result that problems in relation to the thermal environment remain.

In concrete terms, the floor surface temperature and indoor temperature in the living room, as shown in Figure 5 and Figure 6, were below that achieved by the conventional system, which leaves open the possibility that the thermal comfort felt by the occupants might also be slightly reduced. Additionally, the floor surface temperature in the dressing room, as shown in Figure 7, was approximately 20˚C, which means that it was possible to increase the temperature by about 5˚C from its starting point. However, we were unable to produce the same level of thermal comfort as the living room, which the conventional system was able to achieve. On the other hand, the room temperature, as shown in Figure 8, of around 16.5˚C was an increase of around 1.5˚C from its starting point; we were able to confirm the achievement of a slight heating effect from the returning water. However, it is desirable from a health standpoint, for the temperature of the dressing room to be at least 17˚C or greater, and we were unable to reach this target temperature.

Because of the above problems in relation to the thermal environment, the trial system cannot be considered as suitable for installation in houses with a heat loss coefficient of around 2.7W/m^2 K. However, in the case of houses with highly insulated specifications and which have a lower heating load, we think it could be possible to construct a similar floor heating system with higher efficiency.

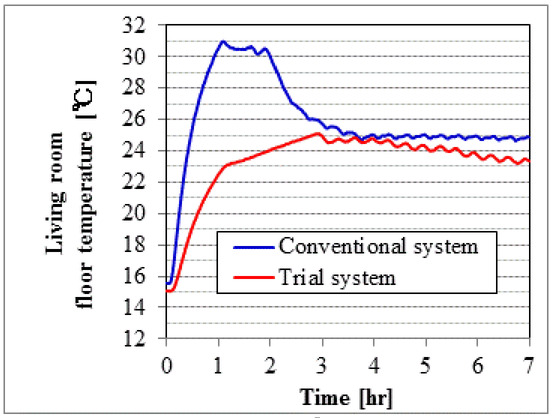


Fig.5 Living Room Floor Temperature

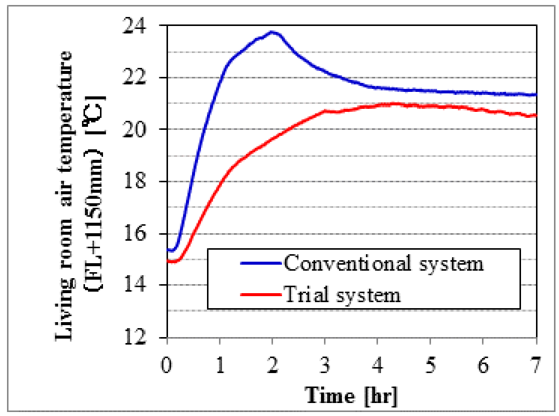


Fig.6 Living Room Air Temperature

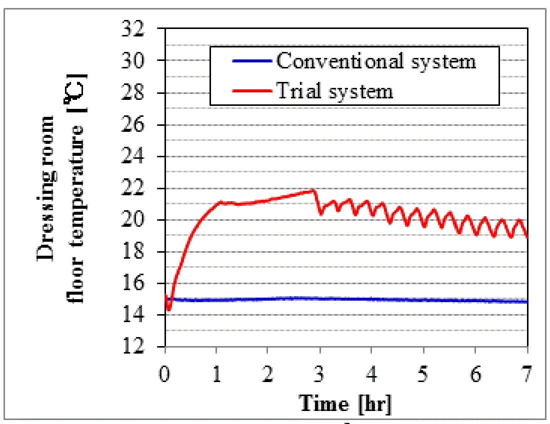


Fig.7 Dressing Room Floor Temperature

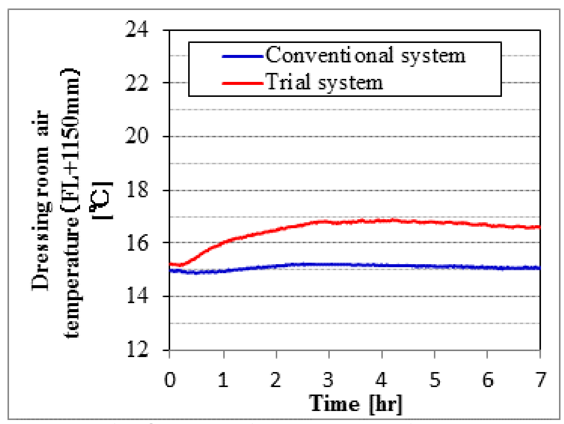


Fig.8 Dressing Room Air Temperature

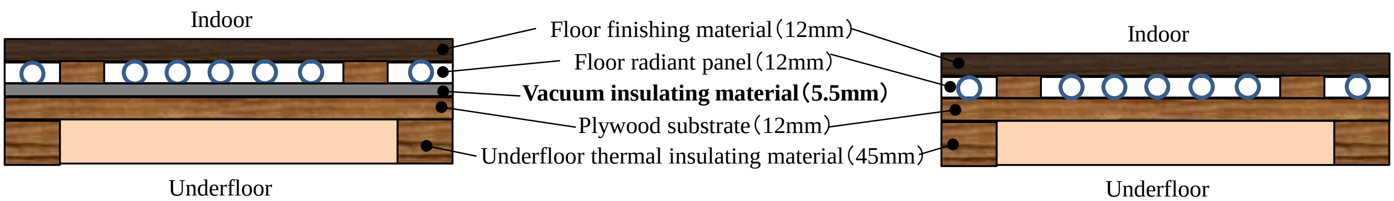
2.2 Increasing indoor heat release rate of floor radiant panels

As a means of increasing the indoor heat release rate, we made efforts to develop thermal insulating material capable of reducing the underfloor heat loss. For the trial system, we adopted a vacuum insulating material with a higher insulating effect than the generally used materials such as resin and glass wool. And by placing the materials beneath the floor radiant panels, we aimed to reduce the loss of radiant heat beneath the floor.

For the evaluation, we installed two types of system, as shown in Figure 9, and measured the indoor heat release rate of each of those systems. In the conventional system, to simulate installation in a new detached house as shown in Figure 2, we installed a 12 mm thick plywood substrate on top of underfloor insulating material with a thickness of 45 mm, and on top of this we installed floor radiant panels with a thickness of 12 mm. The floor finishing material was used a 12 mm thick wooden floor board. The difference in the trial system from the conventional system was the installation of vacuum insulating material with a thickness of 5.5mm underneath the floor radiant panels.

The main test conditions are shown in Table 2. The floor radiant panels used existing components with dimensions of 1470 mm x 3030 mm, and hot water was supplied at the standard design flow rate of 1.0 L/min. The water temperature was set at 60˚C, the same as during standard operation of conventional gas hot water floor heating systems. In order to measure the indoor heat release rate in a condition where the volume of heat radiated from floor radiant panels was sufficiently stable, we conducted the measurements at the point in time where four hours had elapsed since the start of hot water supply to the panels.

The result of the above measurements, as shown in Figure 10, is that the trial system achieved an increase in the indoor heat release rate by 10% compared to the conventional systems. That is, we were able to confirm that by installing vacuum insulating material with a thickness of 5.5 mm, we could reduce the radiant heat loss from the undersurface of the floor radiant panels by a large amount.



(a) Trial System (b) Conventional System

Fig.9 Comparison of Test Systems

Table 2 Test Conditions

Condition	Specified Value
Dimension of floor radiant panel	1470 mm x 3030 mm
Flow rate of hot water supply	1.0 L/min
Water temperature	60˚C
Operating time from the start of hot water supply to the start of measurements	4 hours

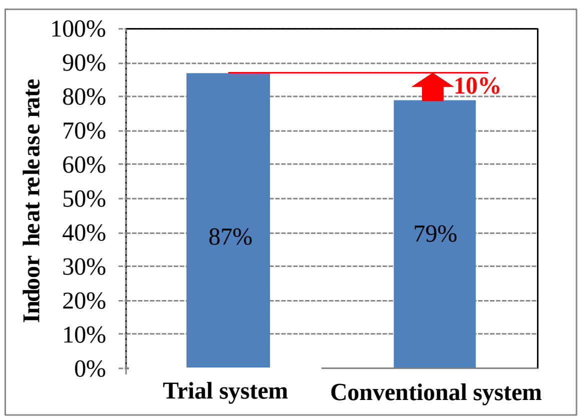


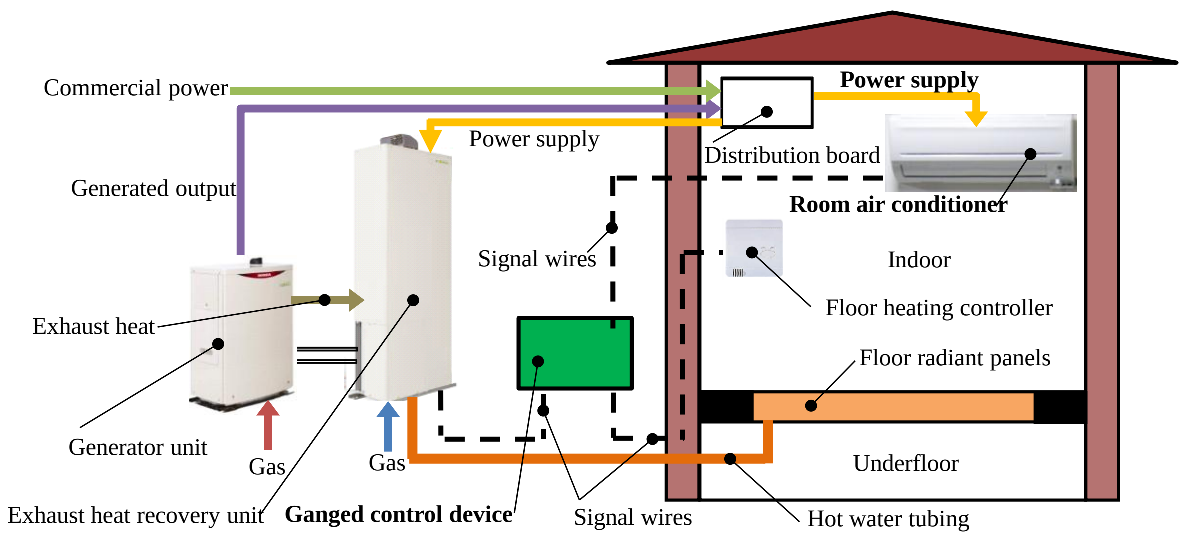
Fig.10 Indoor Heat Release Rate

3. System-wide improvement of home heating efficiency

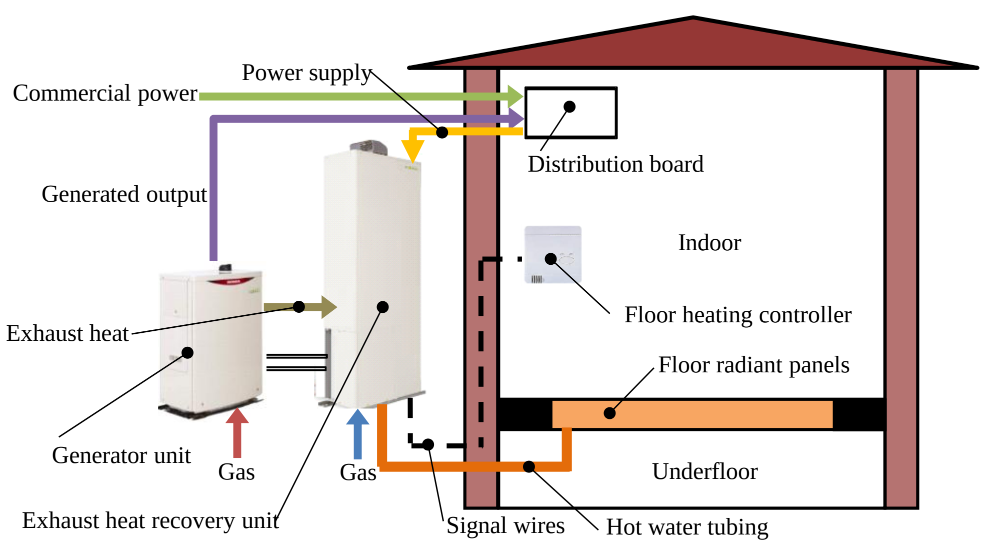
In Japan, the vast majority of houses have electric heat-pump style air conditioners installed, and in recent years, these devices have become able to produce a heat energy output of five to six times their electricity consumption. On the other hand, the popularity of gas cogeneration systems, which generate electricity using gas powered generators and use the exhaust heat generated to heat water for heating systems and general use, has increased in recent years and cogeneration systems have been installed in areas of high demand. Their strong point is that they are designed to save energy by using both the generated power and exhaust heat efficiently.

Based on the strengths of the two different systems above, for this evaluation, we tested a system combining gas cogeneration and ganged control of electric heat-pump style air conditioner and floor heating with the aim of system-wide improvement of the home heating efficiency.

In this evaluation, we installed two types of gas powered generator/ hot water heating systems, as shown in Figure 11, in the test house inside the artificial climate chamber. The conventional system was composed of a generator unit that generates electricity using a gas engine, a exhaust heat recovery unit that used the exhaust heat to heat and store water for heating in a tank, and floor radiant panels installed inside the test house, together with a floor heating controller. The rated power generation output of the generator unit was 1.0 kW, and the rated exhaust heat output was 2.2 kW. The capacity of the exhaust heat recovery unit tank was 137 L and the temperature of the stored water was approximately 75˚C. In addition, an auxiliary boiler was supplied for use in situations where the temperature of the water stored inside the tank was insufficient to meet the hot water or heating demands of the test environment. The exhaust heat recovery unit was connected to the floor radiant panels by hot water tubing and to the floor heating controller by signal wires.



(a) Trial System



(b) Conventional System

Fig.11 Comparison of Test Systems

By comparison, in the trial system, an electric heat-pump style air conditioner was installed in the same room as the floor radiant panels. Also, a ganged control device was installed in order for ganged operation of the floor heating and the air conditioner, and this was connected to each of the exhaust heat recovery unit, floor heating controller, and the in-room component of the room air conditioner, by signal wires. Therefore, whenever the users operated the floor heating controller, information about the operating status of the floor heating system (such as when it started or stopped) was transmitted to both the ganged control device and the exhaust heat recovery unit. Based on this operating information, the ganged control device controlled the operating status of the room air conditioner and made ganged operation of the floor heating and the room air conditioner possible. Further, by powering the air conditioner with electricity generated by the gas cogeneration, and using the exhaust heat of the power generation to warm up water for the floor heating, we aimed to increase the overall efficiency of the home heating system as a whole.

The main test conditions were as shown in Table 3. The heating was set at equivalent to 22˚C. Based on the Japanese energy conservation standards for the heat loss coefficient of new detached houses in a metropolitan area of 2.7 W/m^2 K, the test house was constructed with a heat loss coefficient equivalent to this standard value. The floor surface area of the room was approximately 26 m^2, which was equivalent to the size of the average living room in houses in Japan. The load applied is the M1 standard mode introduced according to the energy conservation standards. The M1 standard mode is a standard load mode envisaging a standard activity pattern of a four person household, in respect of each of electricity, hot water supply, bathwater reheating, and heating. Also, simulate the temperature conditions in winter, the outdoor air temperature was set at 7˚C and the temperature of the supplied water was set at 9˚C.

The air conditioner was operated until one hour had elapsed after the start of operation of the floor heating. In cogeneration systems, learning functionality is included that automatically studies the power usage conditions based on past usage of power, hot water, heating etc., and then carries out power generation at the times of least energy consumption. In consideration of the effect of this learning functionality, each system was operated for 14 consecutive days and the data from the 8th to 14th days was applied when evaluating the functionality of the systems.

For each system, we measured the volume of gas consumption of the generator unit and the exhaust heat recovery unit, the amount of electricity generated by the generator unit, and the amount of power purchased from commercial power suppliers. The result was that, as shown in Figure 12, we were able to confirm that there was a reduction of around 5% on the daily average of primary energy consumption of the trial system, compared to the conventional system. No difference could be seen in the amount of electricity generated by the generator unit, as shown in Figure 13, for either system. However, by compensating for one portion of the heating load with the air conditioner, the amount of gas used by the auxiliary boiler in the exhaust heat recovery unit was reduced, resulting in the reduction in energy usage noted above. Further, we confirmed the daily average gas usage of the auxiliary boiler was reduced by around 18%.

Table 3 Test Conditions

Condition	Specified Value
Heater setting in living room	Equivalent to 22˚C
Heat loss coefficient of test house	Equivalent to 2.7 W/m^2 K
Living room floor area	Approx. 26m^2
Load	M1 Standard Mode (Electricity / Hot Water Supply / Bathwater Reheating / Heating)
Outdoor air temperature	7˚C
Temperature of supplied water	9˚C
Conditions for air-conditioner operation (Only applying to trial system)	1 hour after floor heating starts operation
System operating time	14 days of continuous operation
Data applied for evaluation of functionality	Data from 8th to 14th days

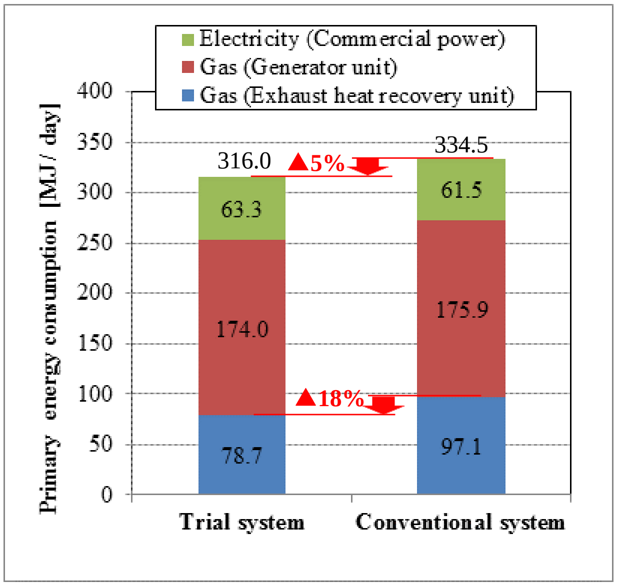


Fig.12 Primary Energy Consumption

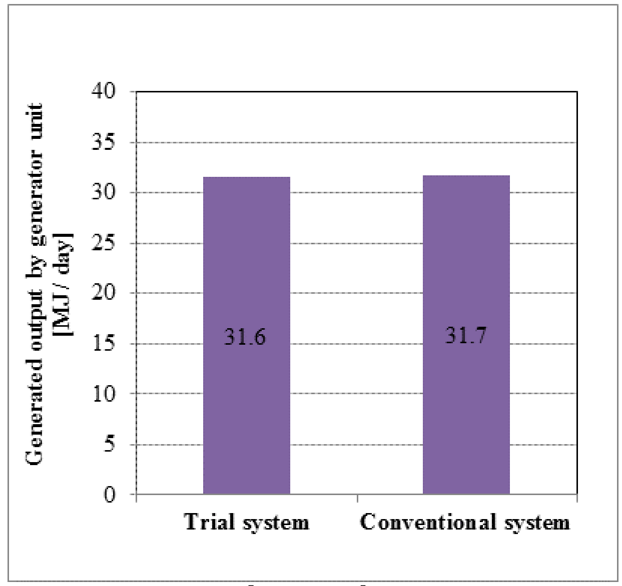


Fig.13 Generated Output by Generator Unit

4. Energy saving effects caused by thermal comfort of floor heating systems

Here we introduce the research results of a survey that Matsumae et al. conducted in relation to the energy saving effects caused by the thermal comfort of floor heating [1]. This research was a survey of eight male survey participants in their 20's who reported on their feelings of thermal comfort or discomfort inside the living room of the test house inside the artificial climate chamber while the room was heated by floor heating or room air conditioner. In each case they commenced the survey when the air temperature in the room reached a sufficiently stable condition.

The participants in the living room were directed to adopt the following two seating patterns. One pattern was to sit on the floor in a posture with their legs stretched out and both hands touching the floor (legs stretched), and the second pattern was sitting on a chair in a posture with both arms stretched out downward (seated in a chair).

The feeling of thermal comfort was set at four levels, ranging from 0 to -3. 0 indicated comfortable, -1 slightly uncomfortable, -2 uncomfortable, and -3 extremely uncomfortable. The participants reported their degree of comfort or discomfort within this range.

The result of establishing the relation between the room air temperature in the vicinity of the participant (FL + 1100 mm) and the participants' feeling of thermal comfort, as shown in Figure 14, is that they discovered it was possible to lower the room air temperature when using the floor heating by around 2˚C, compared to when using the room air conditioner, while maintaining an equivalent level of

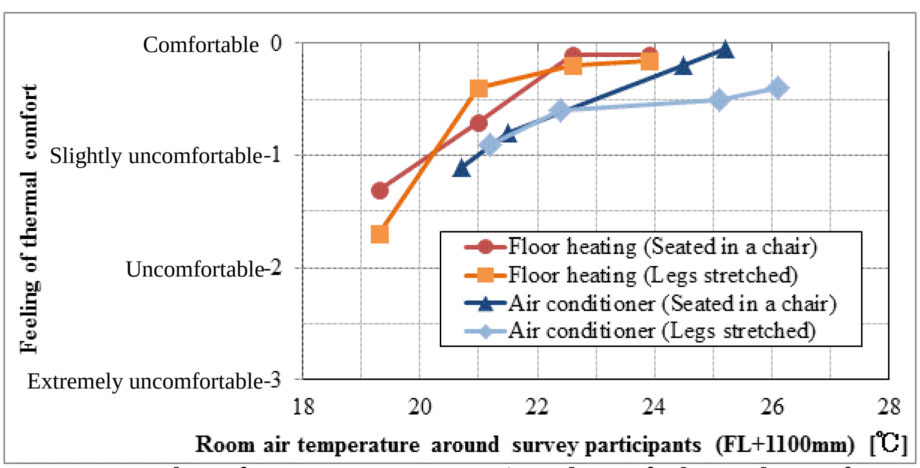


Fig.14 Index of Survey Participants' Feeling of Thermal Comfort

thermal comfort. This is thought to be because, when using the floor heating, the heat radiated from the surface of the floor and transmitted through the participants' feet warms the participants' entire body.

5. Conclusions

In this paper, we introduced some attempts to develop technologies to contribute to increasing energy efficiency of gas hot water floor heating systems as a means of meeting Japanese energy conservation standards. We also introduced results of the survey research related to gains in energy efficiency as a result of the thermal comfort of floor heating systems. The main conclusions that were obtained are set out as follows.

We confirmed that when the floor radiant panels in two rooms are connected in series, the amount of primary energy consumed was reduced by approximately 9% compared to existing systems. On the other hand, because of the reduction in the circulation flow of hot water due to increased pressure loss, problems in relation to the thermal environment remain. However, in the case of application to a house with high insulation specifications, and thus a small heating load, we think it could be possible to construct a similar floor heating system that achieved greater efficiency.

Although vacuum insulating material is thin, it has a high insulating effect, and in the case of the vacuum insulating material with a thickness of only 5.5 mm that we installed beneath the floor radiant panels, we confirmed an increase of around 10% in the indoor heat release rate compared to the case with no insulating material.

In a system combining ganged control of room air conditioner and floor heating with gas cogeneration, where the air conditioner was operated using power generated by cogeneration, we confirmed that by heating water using the exhaust heat from power generation and using this to operate the floor heating, it was possible to reduce primary energy consumption by approximately 5% compared to conventional systems.

It was possible to lower the room air temperature when using the floor heating by around 2˚C, compared to when using the room air conditioner, while maintaining an equivalent level of thermal comfort. This is thought to be because, when using the floor heating, the heat radiated from the surface of the floor and transmitted through the survey participants' feet warms the participants' entire body.

References

[1] K. Matsumae et al., Summaries of technical papers of Annual Meeting Architectural Institute of Japan. D-2, Environmental engineering II, 439-440, (2007).