A STUDY ON THE APPLICABILITY OF THE TIME-DIVISION HOT-WATER SUPPLY HEATING FOR ONDOL - THE RADIANT FLOOR HEATING SYSTEM IN KOREA

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ABSTRACT

The typical Korean residential buildings, especially apartment buildings, are furnished with ONDOL – the Korean traditional radiant floor heating system. The buildings are getting more insulated and air tight for heating in hard winter. ONDOL floors and walls are heavy enough to take up large thermal capacities for the better efficiency of the heating system.

The developed computer simulation program could well predict that the heat- equivalent to 5 continuous hours of hot water supply - is intermittently supplied even on the coldest day in Seoul, Korea. Since heat supply to the buildings with large thermal capacity is intermittent, one space can be heated, while the other cools down slowly with previously stored heat. This concept of heating is proposed as 'The Time-Division Hot-Water Supply Heating System'.

To verify the applicability of the proposed heating system, computer simulation was performed on two identical Ondol rooms. The results showed that the required heating time of each rooms was the both 5 hours, and could maintain room air temperatures even better.

INTRODUCTION

The Building should be supplied with the right amount of heat at the right time in order to manage it in comfort and be able to conserve energy. It is a problem that time and heat supply depend on the thermal characteristic of the building, these variables are coupled each other, and many combinations can take place. In other words, it matters when and how much heat is supplied to the building.

Thermal mass, especially that in the envelope, reduces peak cooling and heating loads; thus it can save equipment capacity (Kreider 1994, KICT 1996). Additionally, it can delay the heat supplied due to thermal storage effect.

In Korea, the capacity of power plant of apartment buildings is determined accoriding to the steady-state load calculation where thermal storage effect is neglected. Heat is supplied intermittently according to a schedule. As district heating system is applied lately, heat is supplied continuously and the amount of heat can be controlled by a room thermostat controller.

The present residential buildings are so heavy that they have large thermal capacities. And they are constructed as more insulated and air-tight. So KICT(1995) reports that room temperature could be maintained with about 7 hours of intermettent heating under peak load condition. This means that it is possible to make use of thermal storage effect.

REVIEW OF ONDOL HEATHING SYSTEM

1. Thermal Characteristics of Ondol Room

Ondol room is made up of a floor, walls and windows. A floor is covered with Ondol panel where the heat is supplied.

The floor is composed of 110–120mm Ondol panel and 250–300mm concrete slab.(MOCIE 1996) This implies that its thermal capacity is about 377kJ/°C/m^2. Walls are made of brick and concrete and their thermal capacities amount to 419kJ/°C/m^2 approximately.(MOCIE 1997) Accordingly, an Ondol room's thermal capacity is 796kJ/°C/m^2.

This means that room air temperature is not affected easily by a variation of outdoor air temperature. It also means there could be much difference between the result of steady state calculation and that of real world. (Kreider 1994) In addition, room air temperature is rarely affected by infiltration owing to air-tight windows. (KICT 1994)

The thermal characteristics of Ondol room, founded by Kim(1992), Yoon(1992), Sohn(1992), Park(1992), and Ahn(1993), are as follows.

It takes up to 2 hours for Ondol that the room air temperature reachs the set temperature after Ondol panel is heated on. The room air temperature is maintained constant by means of thermal storage effect of walls as well as Ondol floor. The apartment building with Ondol heating system ensures thermal storage within building itself due to the structure of building and the characteristics of heating system.

The peak heating load by unsteady-state calculation is about 28 to 40 % less than that by steady-state calculation.

2. Ondol Heating System

Ondol heating system is classified into individual heating system, central heating system, and district heating system according to the heat supplier. Also it is divided into intermittent heating and continuous heating according to the time of heat supply.

2.1 Intermittent Heating System

The features of the intermittent heating system, which supplys the heat according to a given schedule, are as follows. (Park 1992, MOST 1989)

This system is applied to most apartment buildings nowadays. For energy, however, this system comsumes 26–32% more than other system and has a tendency to overheat the buildings. The wide-ranging change of room temperature makes thermal condition unpleasant.

The frequency of hot-water supply for heating is from 2 to 4 times a day for most housing complexes. The time of heat supply is basically 4:00a.m.–7:00 a.m. and 5:00 p.m.–8:00 p.m.. Additional heat supply, if any, is determined mostly by operater's experience.

Despite the drawback mentioned above, the system is simpler than contiuous heating system and more convenient to manage. That's why this system is applied to many residential buildings until now.

2.2 Continuous Heating System

All households are supplied with heat for 24 hours per day. Each household can regulate the room air temperature by a room thermostat controller whenever necessary. Actual operation, however, depends on not the room thermostat controller but an occupant, who controls heating on and off by his own experience. From the viewpoint of heat supply, it is similar to intermittent heating system.

According to Lee(1995), the time of hot-water supply for heating averages 6–7 hours per day. As the room thermostat controller was set to 25°C, the average time for heating in a day was about 4 hours in February and March, and about 3 hours in April. In February, hot-water for heating was supplied continuously for 30 minutes to 1 hour and then stopped. This process was repeated periodically for a day.

In March and April, the break time of heat supply tends to decrease. Heating time at which hot-water supply was concentrated was in the evening and in the morning. As outdoor temperature rised, there were clear distinction from heating time and non-heating time. It means that room temperature can be maintained at 25°C without hot-water supply for continuous heating system.

3. Discussion

For the Ondol rooms of residential buildings in Korea, the large thermal capacity of wall and floor makes the thermal environment of the Ondol rooms change slowly.

In terms of heating system, intermittent heating system tends to concentrate heat supply and make rooms overheated. Thus, energy is consumed more than needed. In order to solve this problem, heat supply is scattered out during a day in a continuous heating system. However, according to the thermal features of residential buildings, heating time and non-heating time is separated, hot-water get supplied periodically, and heating works intermittently.

For energy efficient heating, both thermal storage effect of building structure and intermittent feature of heating system should be taken into account.

TIME-DIVISION HOTWATER SUPPLY HEATING SYSTEM

1. Concept

For two rooms with identical envelope structure, the same amounts of heat have to be supplied to keep the same room air temperatures regardless of Ondol panel structures. According to Cho(1987), the fuel consumption rate does not depend on the thickness of Ondol floor.

If one room can be heated, while the other room is warm by thermal storage effect, the system load can be reduced and the size of plant can be decreased accordingly. The size of equipments and pipes for heat distribution can be saved also. And it could be expected that the life span of heating equipment will be prolonged because of the temperature difference between supply and return hot-water.

In this paper, the time-division hotwater supply heating system is proposed and its applicability is evaluated.

2. Time-Division Hot-water Supply Heating System

The time-division hot-water supply heating system is a system to heat zones by supplying heat in turns. One zone is heated while the other zone is not heated but within a set temperature range. If this system is applied to the residential building, which consists of many households and rooms, it is fit into to two Ondol room. as a basic unit. Figure 1. shows its configuration and control system.

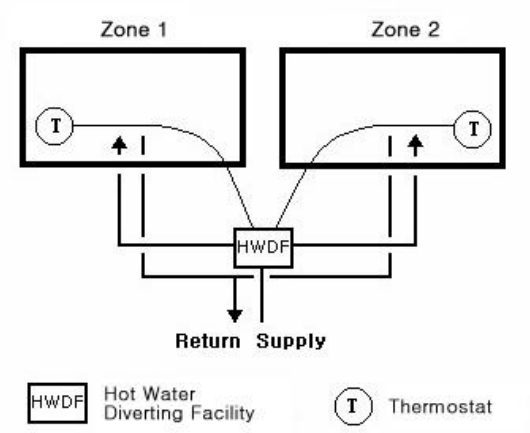

Figure 1. Control System for the Time-Division Hot-Water Supply Heating

Hot-water diverting facility and thermostats are installed in each division zone. The room air temperatures of each division zone, ie. room, are sensed and transferred to the hot-water diverting facility where the hot-water supply is controlled. Thus the amount of heat for division zones is simultaneously controlled.

The time of hot-water supply is determined according to the load difference between division zones. Through the comparison of current room air temperatures with the set temperature, it is determined to which division zone the hot water has to be supplied for. Hot water will be supplied to the division zone of lower room air temperature. Both the hot-water and the amount of heat supplied to each division zone are controlled simultaneously.

The control strategies for this system are as follows. The algorithm of their implementation is shown as a flowchart in Figure 2.

(1) If the room air temperature of a division zone is lower than the heating-on point, then hot water supply starts.

(2) If the room air temperature of a division zone is higher than the heating-off point, then hot water supply stops.

(3) Two division zones will not be heated simultaneouly.

(4) If division zones need to be heated simultaneouly, the division zone with the lower room air will be heated first.

(5) If the room air temperatrues of both zones are the same, the first ordered division zone will be heated.

With this system, it is expected that heat supply for two division zones would be evenly distributed as shown in Figure 3. The room air temperatures would vary as shown in Figure 4.

First, if two zones need to be heated at almost the same time, hot water will be supplied to the zone with the lower room air temperatue as in period(a) of Figure 4. As the room air temperature of division zone 2 drops to the heating-on point, the heat supply is diverted to the division zone 1. Consequently the time of room air temperatures within the set temperature range is extended.

After a certain amount of heat is stored, two zones are heated in turns. The period (b) of Figure 4 shows how the room air temperatures of two zones will be maintained. It is expected that the room air temperature profile of this system will be similar to that of the continuous heating system.

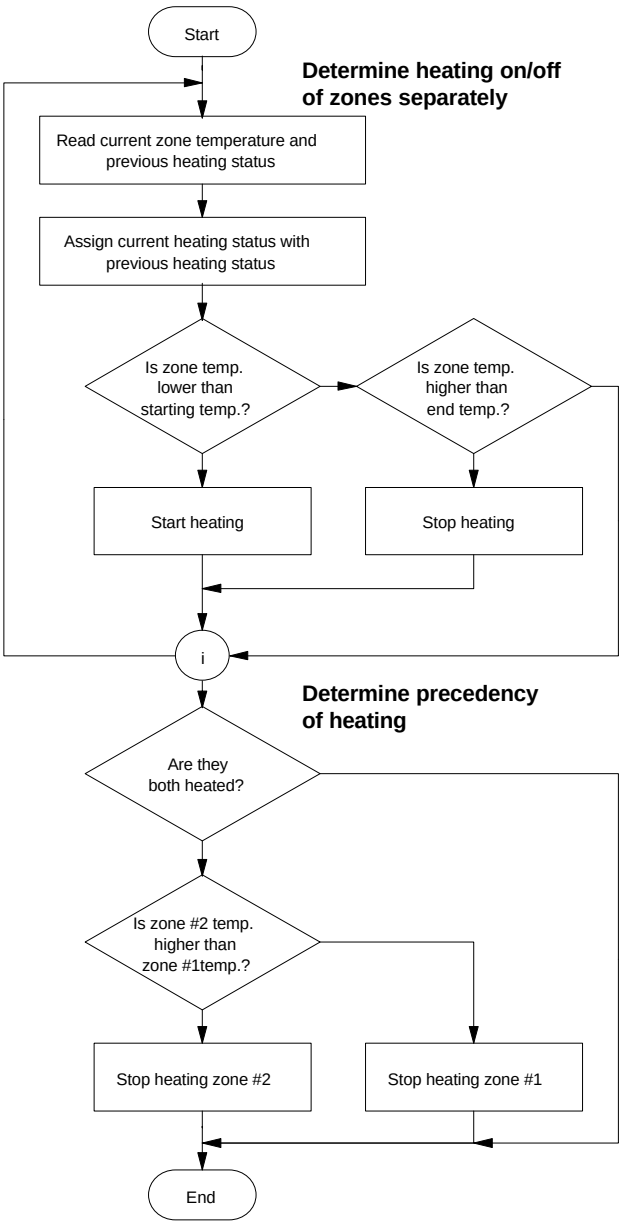

Figure 2. Algorithm for the Time-Division Hot-Water Supply Heating System

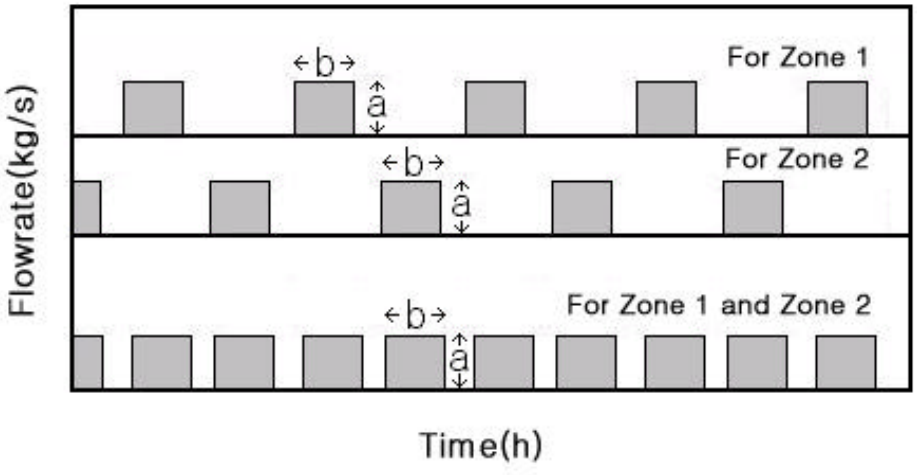

Figure 3. Heat Supply by the Time-Division Hot-Water Supply Heating System

EVALUATION OF APPLICABILITY OF THE TIME-DIVISION HOT-WATER SUPPLY HEATING SYSTEM

In order to evaluate the applicability of the proposed system, the computer simulation is adopted and the thermal characteristic of Ondol room of the time-division hot-water supply heating system is compared with existing heating system(continuous heating system).

1. Simulation Condition

(1) The room for simulation : The typical Ondol room in mid-floor of apartment building is selected. The room has one wall faced outside, and ceiling, floor and three other walls are in contact with identical Ondol rooms.

(2) The structure of Ondol floor : The most commonly used Ondol floor structure by the construction companies in Korea (MOICE 1996), it consists of 135mm concrete slab, 60mm ALC, 26mm cement mortar embedded with a 230mm-spaced XL pipe, and 24mm cement mortar as a finish layer.

(3) Outdoor temperature : From the standard weather data of Seoul(SAREK 1992), the coldest day, 29th January, was selected. Simulation was performed for 7 consecutive days of the coldest day.

(4) Setpoint of room air temperature : 22 ± 0.3°C

(5) Temperature of hot-water supply : 60°C

(6) Analysis program : The developed computer program for this research can analyze the thermal behaviour of multi-rooms with unsteady state calculation. The developed program was validated in the previous research.(MOICE 1996)

2. Simulation for the continuous heating system

As shown in Figure 5, the heating time of the Ondol room is 5 hours and 5 minutes even on the coldest day. This is about 1/4.7 of 24 hours and the non-heating time is a lot longer. The thermal mass of Ondol structure, the heavy wall structure, infiltration decreased by the improved windows, and the heavy insulation prolong non-heating time.

This implies that even for a coldest day of a year, an existing system capacity can cover about 4.7 distinct Ondol spaces. The ratio of heating to non-heating time is 1:2–1:2.4 during the early morning and evening, when the heating loads are maximum. This concludes that two or more Ondol rooms can be heated with an existing system. This is a possibility of the time-division hot-water supply heating system.

3. Simulation for the time-divison hot-water supply heating system

The computer program is modified to simulate the time-division hot-water supply heating system. Two identical rooms are compared and are not heated simultaneously. The heat(hot water) is supplied to one Ondol room while the other room within the set temperature range. The results are as shown in Figure 6.

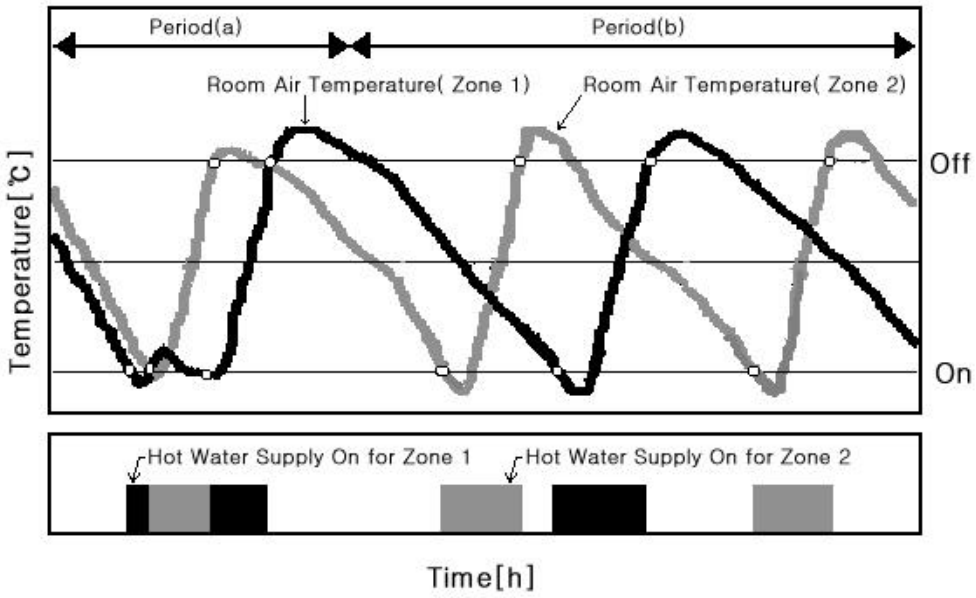

Figure 4. Room Air temperature expected by the Time-Division Hot-Water Supply Heating

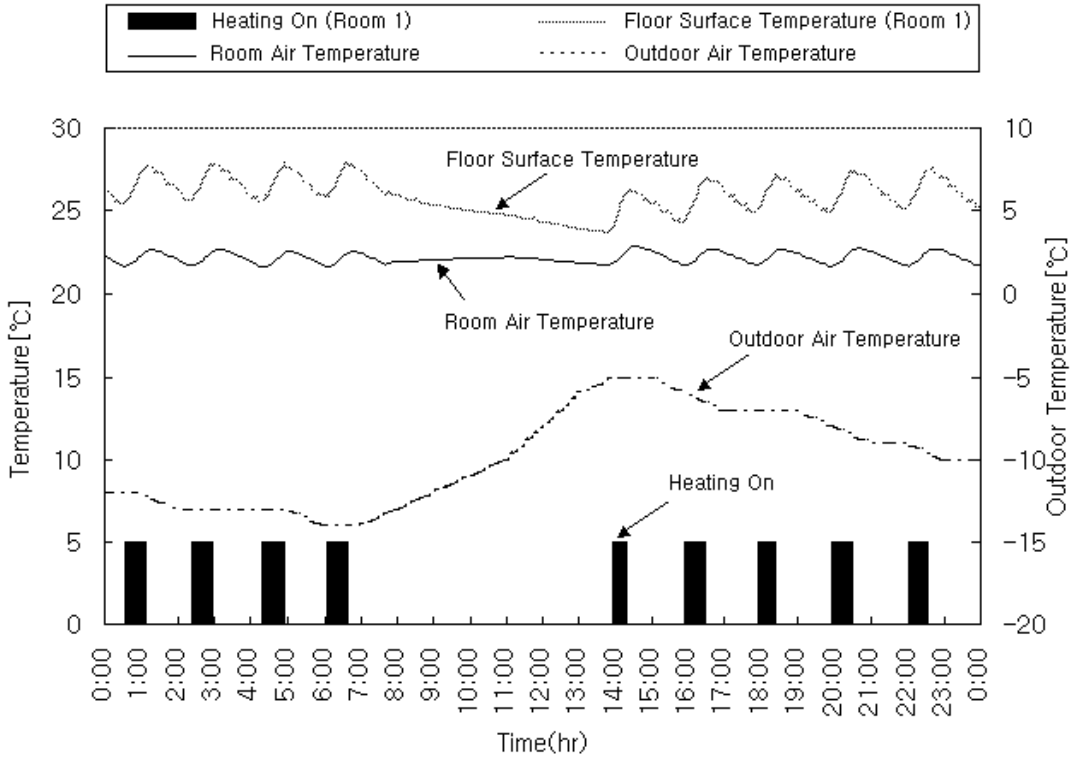

Figure 5. Thermal Characteristic of Ondol Room by the Continuous Heating system

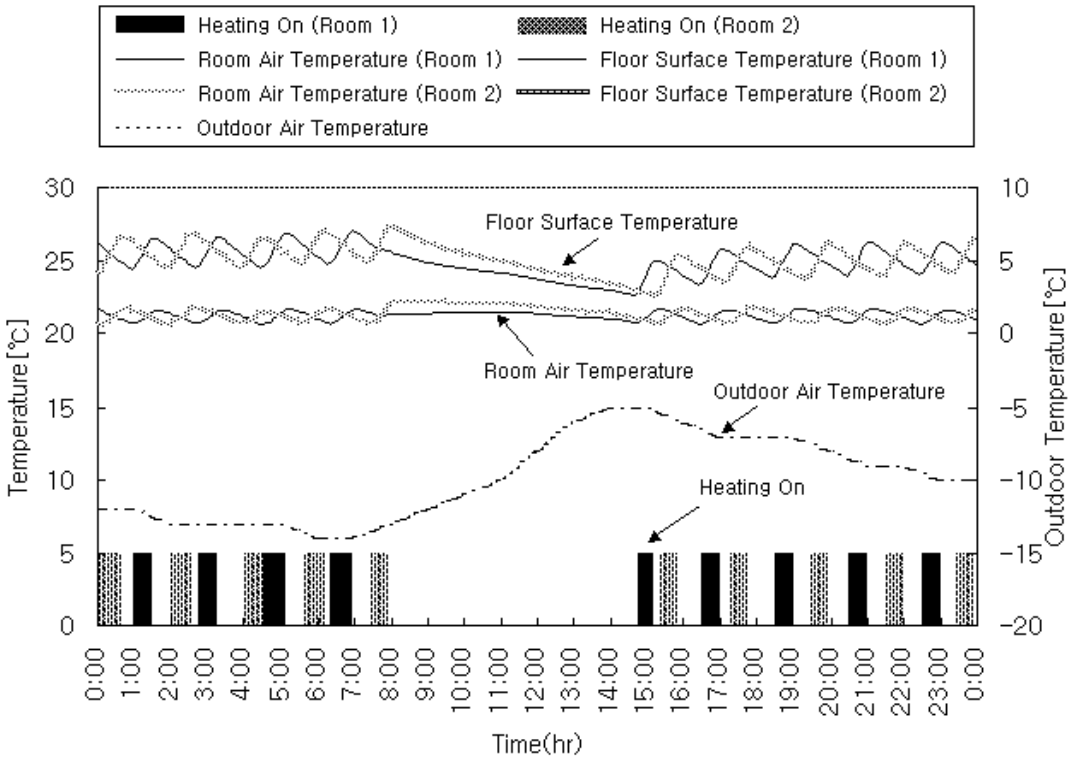

Figure 6. Thermal Characteristic of Ondol Room

by the Time-Division Hot-Water Supply Heating System

The results are compared to the previous system in Figure 5. One system designed for one room could cover two rooms by suppying heat in turns as expected above. The total time of heat supplied is 4 hours and 55 minutes in the previous system. But the total of heat supplied time is 10 hours and 15 minutes after the application of the time-division hot-water supply heating system. The comparison of the two systems are summarized in Table 1 as follows.

The continuous heating system heats two rooms simultaneouly and the time-division hot-water supply heating heats two rooms alternately. For the average and the standard deviation of room temperatures and floor temperatures, there is little difference between the two systems as shown in Table 1. The sum of heating time of two systems are the same. This means that two houses can be heated with the existing pipe system sized for one house.

The ratio of heating time to non-heating time of Ondol room is 1:2 at minimum. So one more Ondol room can be possibly heated while two rooms are not need to be heated. It is considered that three rooms can be heated by the time-division hot-water supply heating system.

CONCLUSIONS

After the analysis of the thermal characteristics of Ondol room, the time-division hot water suppy heating system is suggested, and the applicability is evaluated. The results are summarized as follows.

(1) The literature review shows that heating was on and off periodically to heat Ondol room with intermittent heating on even for the continuous heating system during a day. This proves that the apartment buildings have great thermal storage effects.

(2) Even in the coldest day of a year, 5 hoursof heating was enough to heat Ondol room. The heating time of Ondol room is less than the non-heating time. So the non-heating time of Ondol room need to be made use of for the better system efficiency.

(3) Due to the thermal mass(Ondol panel and walls) of Ondol room, heating time is less than non-heating time at dawn and night, on the coldest period of a day. During the non-heating time of one Ondol room, the other room can be heated by time-division hot-water supply concept.

(4) According to the results of thermal perforamnce analysis simulation for two Ondol rooms, the room air temperature profiles were same as that from the existing heating method. So the applicability of the time-division hot-water supply heating is proved.

(5) The hot water flowrate for one room can cover two rooms without sacrificing thermal comfort of the rooms.

(6) It is expected that the size of pipe, pump and heating equipment can be reduced by adopting new method.

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	Room Temperature				Floor Surface Temperature				Heating Time	
	Mean	Std. Dev.	Max	Min	Mean	Std. Dev.	Max	Min	Room 1	Room 2
Contiuous Heating	22.11	0.31	22.80	21.59	25.90	1.05	27.90	23.70	5:05	5:05
Time-Division Hot-Water Supply Heating	22.25	0.39	22.97	21.58	26.08	1.00	27.96	23.62	5:10	5:05

Table 1. Comparison of the Heating Systems

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