An Experimental Study on Two Parameter Control for Radiant Floor Heating System

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Key Words : Radiant floor heating system, Two parameter switching control, Two parameter on-off control

Abstract

An experimental facility consisting of two 3×4.4×2.8m rooms identical in construction is built. Each room has a control system and storage tank supplying hot water to the radiant floor heating system. The facility enables simultaneous comparison of two different control strategies each implemented in a separate room.

The operating performance of three kinds of flow control scheme is tested and compared in this study : (i) conventional on-off control based on feedback from room air temperature (ii) TPSC(two parameter switching control) (iii) TPOC(two parameter on-off control). Results show that TPSC and TPOC using room air and surface temperature sequentially as feedback signal to control hot water supply is the better temperature regulation scheme than conventional control based on feedback from only room air temperature. They are good candidates for the room with radiant floor heating system under continuous and intermittent heating mode.

1. Introduction

In South Korea, embedded-piping Radiant Floor Heating(RFH) systems are widely used for space heating in residential and multiple unit apartment buildings. Traditionally RFH systems are operated in intermittent mode in order to take advantage of the large thermal storage capacity of the floor slab.

Intermittent heating is not only shown to be cost effective but the practice also enjoys the support of technicians who periodically service the boilers during off periods.

On the other hand, large fluctuations in floor slab temperatures (due to intermittent nature of heating) have contributed to large variations in room air temperatures. Consequently, improving thermal comfort in houses

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has become an important issue.

The problem of heated radiant heat control has been addressed in the literature. Most of these studies have been oriented to the improvement of continuous heating system. Friedlander and Adelman suggested outdoor reset control to improve temperature regulation of radiant heating system. A study by Fort has shown that controller should be installed at each room to be efficient. MacCluer et al. suggested heat flux modulation to give fast response. Berglander et al. have discussed about the performance and operating strategies of radiant and convective heating system. Recently study by Cho et al. has shown that two parameter control by room air and slab surface temperature could be good candidate for radiant heat control. In general modulating controls(either proportional(P) type or proportional integral(PI) type) have been known to improve temperature responses of RFH systems. However, from the viewpoint of costs and to some degree the problems of tuning PI controllers, it is still not feasible to use PI controllers in home heating systems. The practical choice continues to be on-off control. Thus we are interested here in exploring improved on-off controls for RFH systems. Since air temperature alone as a control signal is not likely to improve thermal comfort, we are interested in exploring other control parameters.

In this regard, we are guided by the fact that a majority of South Koreans enjoy sitting on lightly carpeted or mat covered floors. This being the case, large fluctuations in floor slab temperatures are incompatible with thermal comfort needs of the occupants and the residential house should be installed with a room controller to conserve energy by the construction law even on the intermittent heating.

Therefore, we propose a two-parameter control strategy to deal with the floor heating system operated with continuous and intermittent heating mode.

The two-control parameters being the air temperature and the floor slab temperature.

In the following, we describe the experimental facility designed to assess different control strategies. Results obtained with on-off control, and two-parameter controls for the house with continuous heating and intermittent heating mode will be compared. A discussion on the effectiveness of two-parameter control as opposed to conventional on-off control will be given.

2. Experiment

2.1 Experimental facility

The experimental facility consisted of two rooms constructed side-by-side with a common wall as shown in Fig.1. Each room measures 3×4.4×2.8m. Th rooms are facing

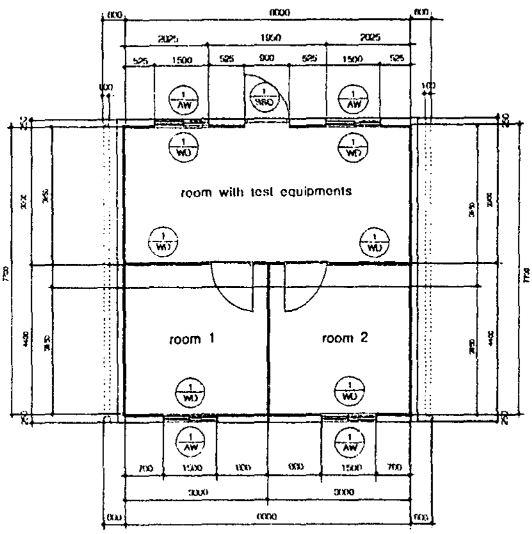


Fig.1 Floor plan of test facility

approximately due south; each room has windows (1.5×1.5m) one on the south wall and the other on the north wall. To eliminate unequal effects of direct solar radiation incident on the east and the west walls sun screens as shown in Fig.1 were installed. And also HVAC system with air conditioning facility (2RT) as shown in Fig.2 was installed to make the identical initial air condition of two rooms fastly. It is available to keep the identical condition of two rooms within ±1℃ limit.

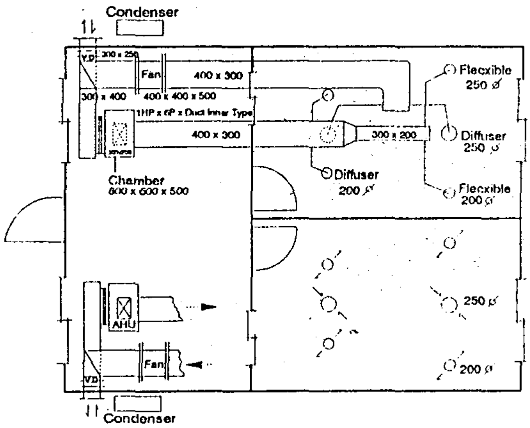


Fig.2 Air conditioning facility

2.2 Floor plan

The overall dimensions of the facility measured 6×8.8×2.8m. Roughly one half of the floor space is used for housing the boilers, piping network, storage tank and data acquisition system and controls.

In effect, this space located at the entrance serves as mechanical and data acquisition control room. The second half of the floor space is where the embedded-piping radiant floor slabs are installed.

The construction details of the radiant floor slab, walls and ceiling etc. conform to the local Korean practice based on design of around $0.5W/m^2h$ heat transfer rate. The embedded-piping floor consisted of 15mm diameter copper tubes installed on 20mm centers.

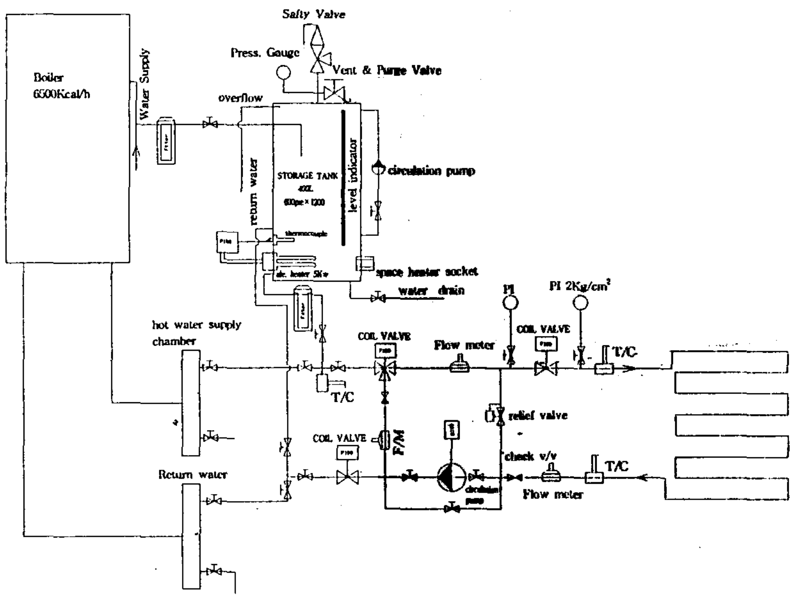


Fig.3 Schematic diagram of heater and control system

2.3 Heating system

The central objective of this experiment was to evaluate the performance of two different control strategies simultaneously under similar environmental conditions with two identical heating system.

As shown in Fig.3, each heating system consisting of a hot water storage tank (20kW) is also installed in the circuit so that hot water from the storage tank can be circulated in the embedded-piping floor slab. This heating arrangement helps in maintaining a close control on the temperature of supply water to the floor slab. The storage tank has a 20kW capacity electric heater, a PI controller to maintain constant temperature of water, a circulation pump for good mixing and a safety valve. In the experiments conducted, hot water to the floor slab is supplied from the storage tank.

The main hot water supply consists of both a three-way valve and a two-way flow control valve. In this study we have used the two-way flow control valve. Supply and return water temperatures were measured by RTD insertion type sensors and the mass flow rate of water was measured by 1~30 liters per minute capacity turbine flow meters.

2.4 Temperature measurements in the rooms

Apart from the room air temperature, outdoor air temperature, measurements were also made of floor-slab temperature close to ther room themostat. Themocouples were embedded in between two adjacent tubes of the floor slab surface.

2.5 Data acquisition and monitoring system

A total of 56 temperature points (28points per rooom) were measured by a multi-channel data acquisition and control system. Two output channels (room air temperature and slab surface temeprature) were used for control. The data acquisition system was connected to a 486PC via RS 232C. A user-friendly program was written for implementation of control strategies. The program works in window environment and displays schematic system, monitoring status and setpoints. The sampling interval of data acquisition can be changed. For the experiments conducted, the data was gathered at every 30 seconds which is too high rate for the slow subsystem such as the floor slab but adequate for the fast subsystem such as the fluid flow in the pipes. Note that a single data acquisition system was used for monitoring and control of individual heating systems and for simultaneous measurements of temperatures in the test rooms.

3. Control strategies

The designed experimental facility is capable of simulating both heat flux modulation and temperature modulation strategies. Here we have investigated three operating strategies : (i) the conventional on-off control based on feedback from room air temperature, (ii) TPSC(two paramenter switching control), and (iii) TPOC(two parameter on-off control) using the floor slab temperature and the indoor temperature sequentially as feedback signal. Here TPSC and TPOC have the similar control algorithm which sequentially checks for the high and low limits of air and floor slab temperatures.

But the former control algorithm(TPSC) has the switching interval for the valve to be operated by the room air temperature and the floor surface temperature. For example if TPSC has 10 minutes switching interval, which means that the valve is operated on-off sequentially in response by the indoor temperature signal during first 10 minutes and during next 10 minutes by the floor slab temperature signal.

In the contrast to the former one, the latter one(TPOC) is that valve is operated on-off based on the lower limit of room air temperature and surface temperature. This means that the valve get opened if any one value of two parameter (room air temperature, slab surface temperature) keeps under lower limit of setting point. Therefore, the valve get closed when two parameters are maintained within the limit or above of setting point.

The previous theoretical study has shown that TPOC is an effective strategy in improving temperature regulation of radiant heating system but can be controlled based on the floor surface temperature. Therefore, we will check experimentally the application feasibility of TPSC for the radiant heating room with continuous heating mode and TPOC for the radiant heating room with intermittent heating mode.

4. Experimental results

The experimental facility was functional during three months (Feb~Apr) of 1996 heating season. During that period, several experiments were conducted to compare the effectiveness of different control strategies.

One test conducted was the application feasibility of TPSC for the residential house with the RFH system under continuous heating mode. For this testing, switching intervals were changed 10 minutes, 20 minutes, 30 minutes, 40 minutes and 60 minutes under two different weather conditions of cold (Feb, Mar) and warm(Apr).

The other test conducted was the application feasibility of TPOC for the house with the RFH system under intermittent heating mode. For this testing, supplying time of hot water to the floor slab was changed to 6 hours, 9 hours and 12 hours.

These two kinds of testings were conducted simultanously with the conventional on-off control based only on the room air temperature and two results were compared.

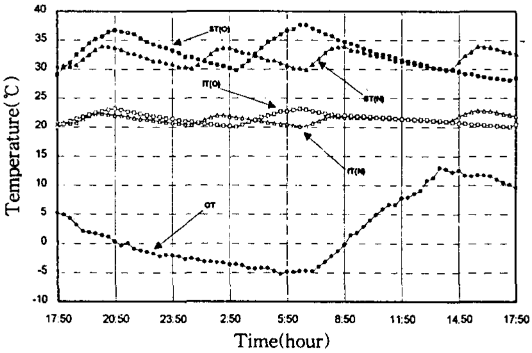
For our experiments the supplying temperature of hot water from water storage tank was maintained constant at 55℃. The room air temperature setpoint was 21±1℃ for the conventional on-off control, TPSC and TPOC. The floor surface temperature setpoint was 31±1℃ for TPSC and TPOC.

The first set of experiments is to compare the operation performances of TPSC and on-off control. The room on the left-side was operated using an on-off control strategy and one on the right-side was controlled using TPSC strategy.

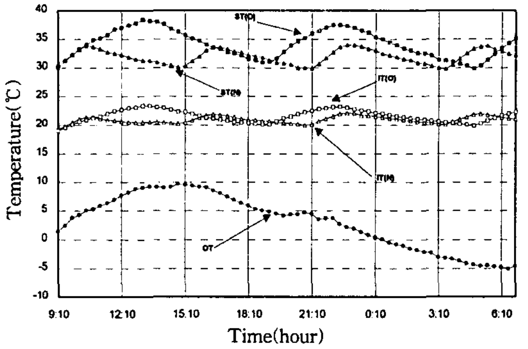
The monitored data are plotted in Fig.4 (a)~(e) for cold weather and Fig.5 (a)~(e) for warm weather.

Figure 4 shows outdoor temperature(OT), floor slab temperature(ST), room air temperature(IT), two parameters switching control (N), and conventional room air temperature based on-off control (O). It was cold days with outdoor temperatures typically raging between -5℃ and -10℃.

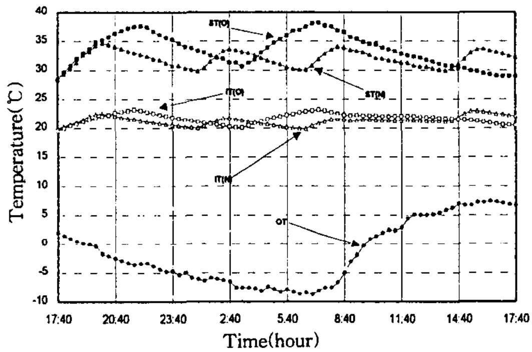
In case of conventional on-off control, it is



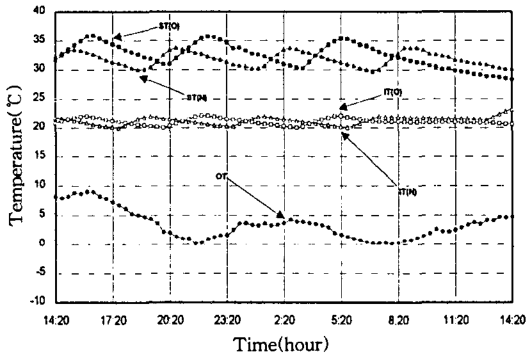
(a) 10 minutes



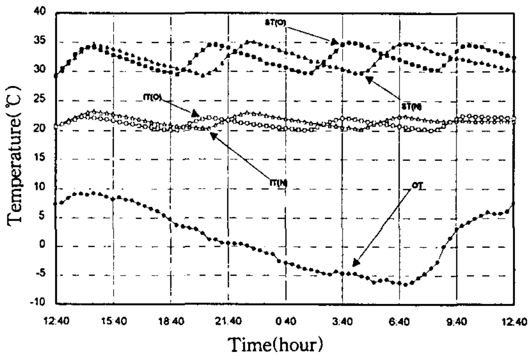
(b) 20 minutes



(c) 30 minutes



(d) 40 minutes



(e) 60 minutes

Fig.4 The variations of switching interval (continuous heating, cold weather) interesting to note that the 24 hour period consisted of 2~3 on-off cycles for the colder day (Fig.4(a)~(c)) and 3~4 on-off cycles for the warmer day (Fig.4(d)~(e)) in the cold weather. These results say that the warmer days give flatter temperature variations and more frequent on-off switchings than the colder days.

When the outside weather was cold (Fig. 4(a)~(c)), the room temperature fluctuated between a high of 23 and a low of 20℃ (3℃ variation) and the corresponding floor slab temperature was from 30 (8℃ variation) to 38. When it was warmer days (Fig.4(d)~(e)), the room temperature underwent 2.5℃ variation (maximum 22.5 and minimum 20℃) and the corresponding floor slab temperature variation was 5℃ (maximum 35 and minimum 30℃).

From this result, it is evident that on-off control based on the room air temperature leads to the higher floor slab temperature variation than the room air temperature according to variation of outside weather condition.

In case of TPSC(two parameter switching control), it is apparent that the room air and the floor slab temperature are maintained within the setpoint limits through more frequent on-off switchings of 3~4 cycle.

The room air temperature underwent 2℃ variation (maximum 22 and minimum 20℃) and the corresponding floor slab temperature underwent 4℃ variation (maximum 34 and minimum 30℃) when the interval of switching hour was 10~40 minutes. But, when the interval of switching hour was 60 minutes, the room air temperature was 2℃ variation and the floor slab temperature was 5℃ variation. These results appeared similar with the conventional on-off control because outside weather was warm. These show that the better temperature regulation could be achived by TPSC only when the interval of switching hour is under 40 minutes.

The fluctuation of the room air temperature by TPSC was almost similar to the conventional on-off control, around 2℃, but the change of floor slab temperature was lessened by about 50%, 4℃ from 8℃.

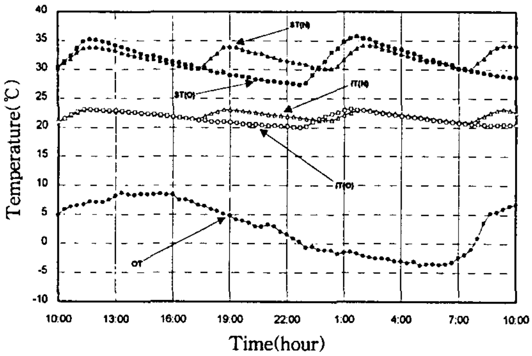
Therefore, the better room circumstance could be achived by TPSC regulation at the residential house under continuous heating mode.

Actual temperature responses of a warmer day (April) by the conventional on-off control and TPSC are depicted at Fig.5 (a)~(e) to check the influence of weather condition. It was a warm day with outdoor temperature raging above 0℃.

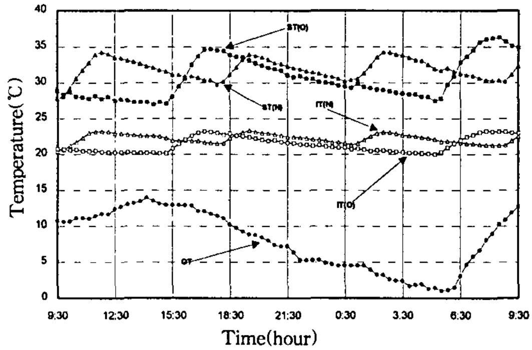
Looking at the response of the conventional on-off control, it is interesting to see that the floor slab temperature was maintained from 25 to 35℃, setting lower temperature distribution and bigger fluctuation than colder weather (Fig. 4.). Relatively the room air temperature was remained close to the setpoint 22±1℃ consisting of only 1~2 on-off cycles. But the results of TPSC operation produced quite different responses. The room air temperature was remained from 21℃ to 23℃ (2℃ variation) and the corresponding the floor slab limits were from 30℃ to 34℃ (4℃ variation) when switching hour interval is in 10~40 minutes.

For the 60 minute switching interval, the similar temperature fluctuation was observed for the two operations of the convention on-off control and TPSC. We couldn't find a big difference in trend between the two cases under the 40 minute switching interval, similar to at the colder weather (Fig.4).

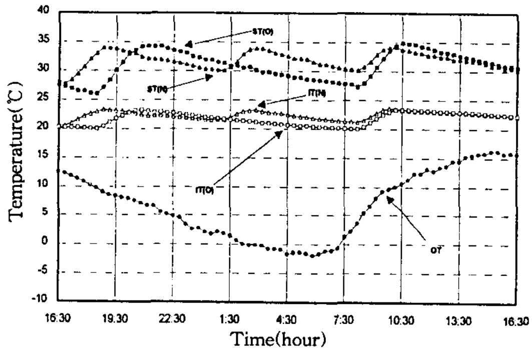
As a result, for the TPSC control with



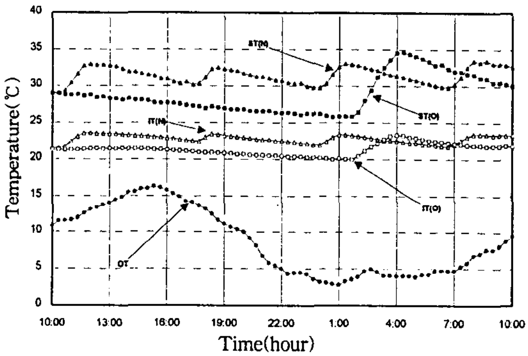
(a) 10 minutes



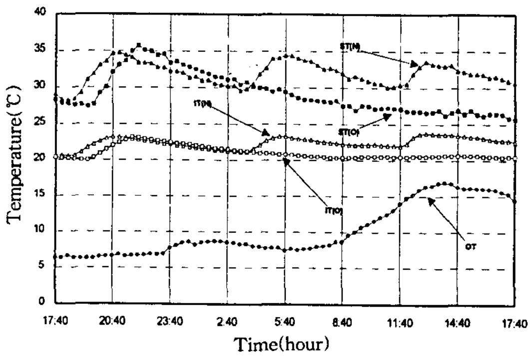
(b) 20 minutes



(c) 30 minutes



(d) 40 minutes



(e) 60 minutes

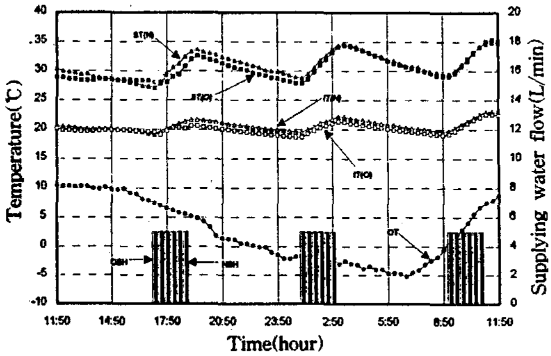
Fig.5 The variations of switching interval (continuous heating, warm weather) under 40 minute switching interval, the variation of the floor slab temperature became lessened more than 50% (from 9℃ to 4℃), giving 1℃ higher room air temperature than the conventional on-off control. This means that being controlled by TPSC the floor slab temperature is more influntial factor than the room air temperature.

Therefore, TPSC strategy could be better controlling mode even on warmer days when adjusted to consider the room air temperature more than the floor surface temperature.

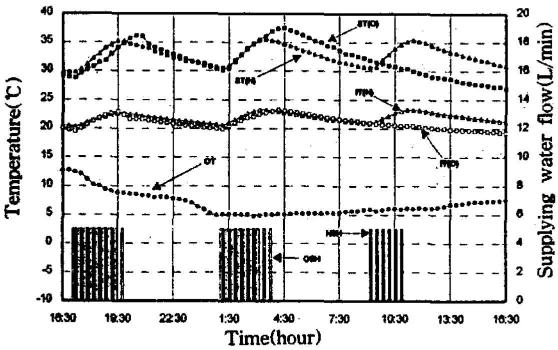
Almost the majority of multiple unit apartment buildings of our country are operated in intermittent heating mode in order to take advantage of their thermal storage capacity of the floor slab. Interestingly, even the multiple unit apartment buildings with intermittent heating mode in Korea should be installed with room controller by the construction law. But if the room air temperature is held constant by the operation of the room controller during heat supplying hour at intermittent heating mode, very bad room circumstance will be met during heat-off mode.

Because of this unfair control mode, at the moment, the majority of room controller installed in Korea multiple apartments with intermittent heating mode are useless equipment. From a speculative point of view, it appears that the use of TPOC may be satisfactory for intermittent heating mode because the room air and floor slab temperature could be positioned on the higher limit of comfort region during heating mode and lower the limit of comfort region during non-heating hour. Thus, we experimented the conventional on-off control and TPOC under intermittent heating mode, changing hot water supplying hours.

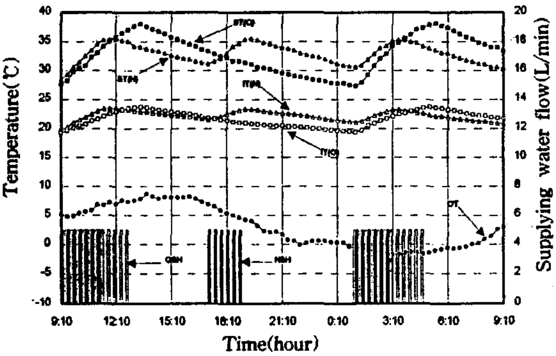
Figure 6(a)~(c) show outdoor temperature



(a) 6 hours



(b) 9 hours



(c) 12 hours

Fig.6 The variations of hot water supplying time (intermittent heating)

(OT), floor slab temperature(ST), room air temperature(IT), on-off control(O) and TPOC (N).

The hot water supplying hours were changed : 6 hours(1~3, 9~11, 17~19), 9 hours (1~4, 9~12, 17~20), and 12 hours (1~5, 9~

13, 17~21). Measurements were made on march, 1996. Fig.6(a) on the case of 6 hours heat supplying showed that the room air and floor slab temperature at the two control modes (on-off and TPOC) maintained almost similar behaviors bacause hot water supplying was not enough to hold the room air within the set point (22±1℃).

In case of 9 hours and 12 hours heat supplying, the room air temperature fluctuated between a high of 24.5 and a low of 19.5℃ (4℃ variation) and the floor slab temperature was from 27℃ to 37℃ (10℃ variation) under the conventional on-off control, consisting of only two times heat supplying among the total three times heat supplying. On the other hand, TPOC held 4℃ variation of the room air temperature (from a high of 23 to a low of 19℃) and 5℃ variation of floor slab temperature(from a high of 35 to a low of 30℃).

Thus, we could see that the flutuation of room air and floor slab temperature could be lessened by about 50% (from 10℃ to 4~5℃) than the on-off control on the overheating to the room if the TPOC has taken into the floor heating system.

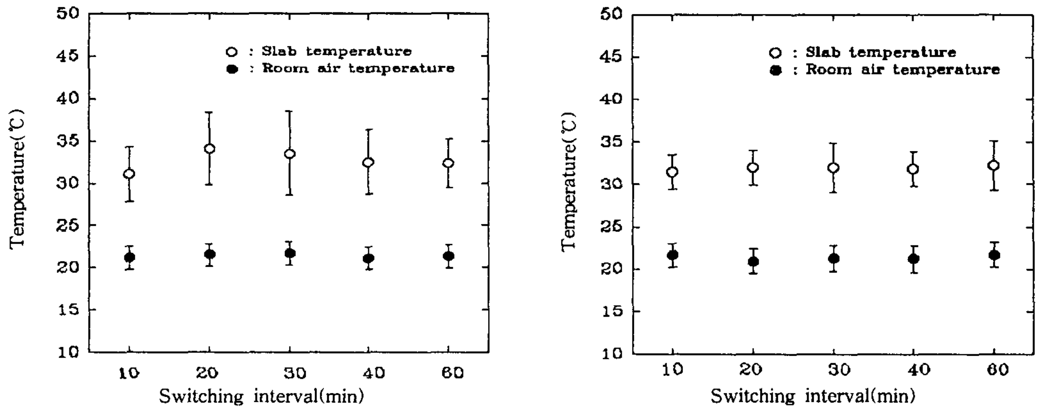
These results conform that better temperature regulation and room circumstance could be achived with TPOC in Korean residential houses with intermittent heating mode.

Average, maximum, and minimum temperatures of the room air and the floor surface over the whole experiment period (24 hours) are shown in Fig. 7~9.

Figure 7 showing the results done by on-off control indicate that the maximum and minimum temperature difference of the floor slab surface appeared on a large fluctuation even though the temperature difference of the room air was small to the outside temperature variation.

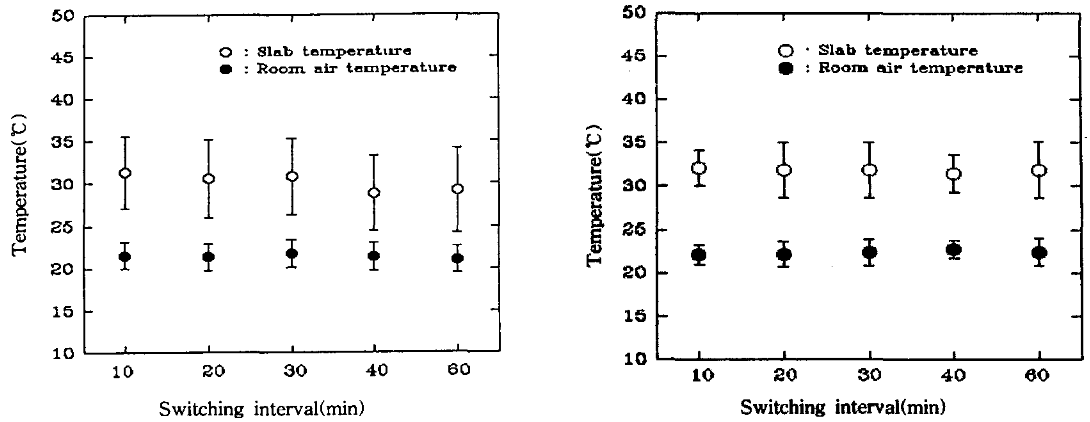
In contrast, Fig.8 operated with TPSC show that the difference of the room air and floor slab surface temperature remained within a small fluctuation even though there is a lot of outside air temperature variation.

From these results, we could see that TPSC is more robost and better regulation tool than the conventional on-off control, even with the variations of outside weather. Fig.9 shows



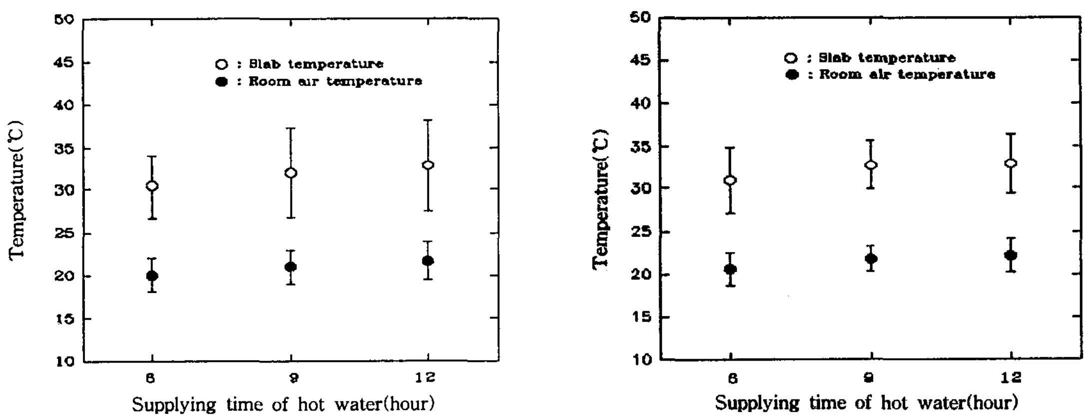
(a) On-off control (b) TPSC control

Fig.7 Average temperature, maximum and minimum temperature difference of the indoor air and the slab (continuous heating, cold weather)



(a) On-off control (b) TPSC control

Fig.8 Average temperature, maximum and minimum temperature difference of the indoor air and the slab (continuous heating, warm weather)



(a) On-off control (b) TPSC control

Fig.9 Average temperature, maximum and minimum temperature difference of the indoor air and the slab (intermittent heating, warm weather)

the results operated by the on-off control and TPOC under the intermittent heating mode.

According to the figures, with an increase in heat supplying hours, the fluctuation of each temperature seemed to be larger on the conventional on-off control. On the other hand, the temperature fluctuation on TPOC appeared to be small and smooth regardless of the heat supplying hours. Therefore, we could conclude that TPOC is an effective controlling mode to improve the room circumstance and protect from overheating the house with floor heating system under intermittent heating mode.

5. Conclusions

An experimental facility consisting of two identical rooms and RFH system is built. The facility enables simultaneous comparison of two different control strategies and similar load conditions.

Results show that the better temperature regulation could be achived by TPSC when the interval of switching hour is under 40 minutes.

TPSC and TPOC using two-parameters for controlling could lessen the fluctuation of room air and floor surface temperature by above 50% and improve the thermal circumstance of house with FHS.

Not having an effect on the outside weather, TPSC and TPOC could maintain the room air and floor surface temperature in the comfort limit. Being simple and cost effective, the both controlling strategies(TPSC, TPOC) are good candidates for the radiant heat control.

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