

A Study on Control Characteristics and Thermal Environmental Analysis of Automatic Thermostatic Valves for Radiant Panel Heating System in Residential Apartments

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ABSTRACT: The control characteristics and heating performances for radiant panel heating system with automatic thermostatic valves in residential apartments are researched by computer simulation and experiments. For the analysis of unsteady heat transfer phenomena in household, the method of using electrical equivalent R-C circuit is applied, and radiation heat transfer between panel, ceiling and walls in household is calculated by enclosure analysis method. As control methods for automatic thermostatic valves, room air temperature sensing method, water temperature sensing method, proportional control method, On-Off control method were applied to research effects on heating performance and control characteristics.

Keywords: Floor radiant heating system, unsteady energy analysis, equivalent R-C circuit, automatic thermostatic valve

1. INTRODUCTION

The radiant heating system for residential house has been developed by architecture and building engineering. A regional climate, thermal conditions of a structure in building, lifestyle and heating equipment is essential factors how to select and operate the heating system.

The radiant panel heating system is simple, the price is cheap, the comfortable feeling is good, initial cost and running cost is few, silent. And it will be able to use the a low hot water temperature in order for the radiant heat area to be wide and there is a advantage will can connect with the heating system which uses a different heat source.

The studies on radiant panel heating system are being performed to maintain comfortably indoor temperature on supply flow rate and supply water temperature. But

according to various heating methods, a dynamic characteristic of indoor temperature and energy consumption changes appeared respectively different. So the energy analysis of indoor space is more important.

Also these heating methods are interlocked with an automatic thermostatic valve to maintain comfortably indoor temperature.

By the way recently a necessity of demand and technology advancement increased about automatic thermostatic valve according to improvement of a standard of living.

In the late 1980s, the ministry of Power Source in Korea made a law that each household should have a automatic thermostatic valve. But most of them used the imported automatic thermostatic valves owing to a lack of domestic technologies and facilities. But imported automatic

thermostatic valves were not fit for the floor radiant heating system in Korea. So recently automatic thermostatic valve with air temperature feedback and water temperature feedback are produced from Korea, but a data and a study on control characteristics and energy-saving performance of automatic thermostatic valve is very insufficient

Thus in this study, the control characteristics and heating performance for radiant panel heating system with automatic thermostatic valves in residential apartments are researched by computer simulation

2. INDOOR THERMAL ENVIRONMENT

Figure 1 shows indoor heat flow. There are 3 routes of conduction heat transfer through the floor, the ceiling and the wall, convection heat transfer with indoor air, and radiant heat transfer between the heated floor and the non-heated ceiling or wall in a household.

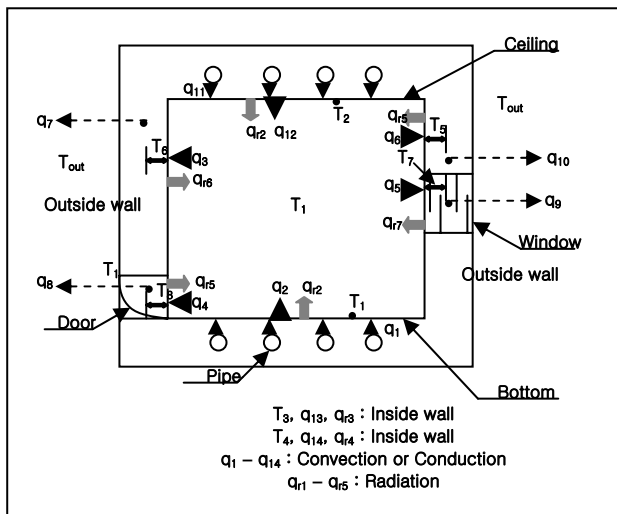


Figure 1: Schematic diagram for heat transfer analysis in room.

The radiant heat transfer is represented by the following equation:

$$q_{rk} = A_k \varepsilon_k \sigma T_k - \sum_{j=1} A_k \varepsilon_k \sigma T_k G_{jk} \quad (1)$$

where

$$G_{jk} = F_{j-k} \varepsilon_k + F_{j-k} \rho_1 G_{1k} + F_{j-k} \rho_n G_{nk}$$

ε : Emissivity

σ : Boltzmann constant

ρ : Reflexibility

F_{j-k} : Coefficient of form between the surface of inside and outside

A : Surface area

T : Surface temperature

q_{rk} : The radiant heat transfer for k_{th} surface

The relationship between the temperature in each part and heat transfer expressed throughout the equivalence R-C circuit method is shown in figure 2. It's based on assumptions that heat amounts for each wall are concentrated to one point, a central node, equivalent heat resistances on either side of those in the wall are the same. Therefore heat loss to outdoor air can be considered from these points.

Thus the energy equilibrium equation is represented by the following equation:

$$C_i \frac{dT_i}{Dt} = \sum q_{in} - \sum q_{out} - q_{rk} \quad (2)$$

Where

q_{in} , q_{out} : The heat transfer by convection or conduction

q_{rk} : The radiant heat transfer

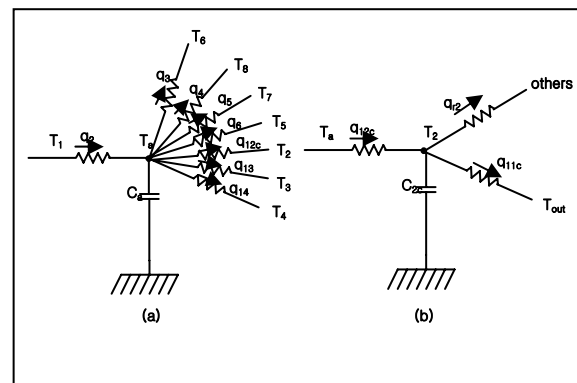


Figure 2: A equivalent R-C circuit for unsteady energy analysis.

3. EXPERIMENTAL EQUIPMENT

Figure 3 shows experimental equipments and a schematic diagram.

In order to supply hot-water of constant temperature in the pipe under panel, stored hot-water could be maintained at the specified temperature through the boiler, heat exchanger, and storage tank.

It's necessary to select center and measure its temperature in the middle position between nearest section of the pipe and its nearest section in the middle point of the room to analysis heating conditions in the room, and thermocouples are used to measure temperature of the room, the wall and the ceiling in the center of each part. A thermocouple, 1.5meters above the ground, is used to gauge the room temperature.

By using the energy analysis program for simulation the temperatures of the indoor air,

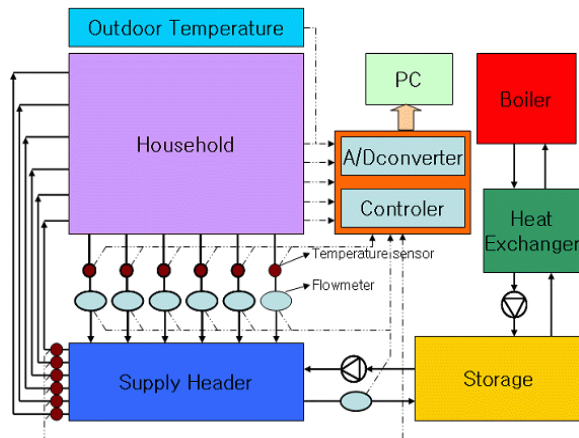
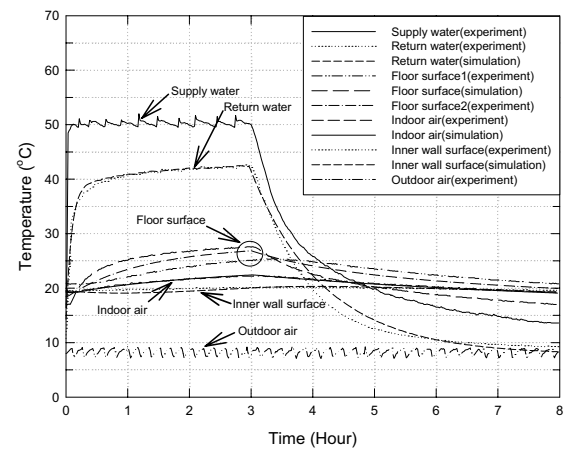


Figure 3: Experimental equipment and a schematic diagram.

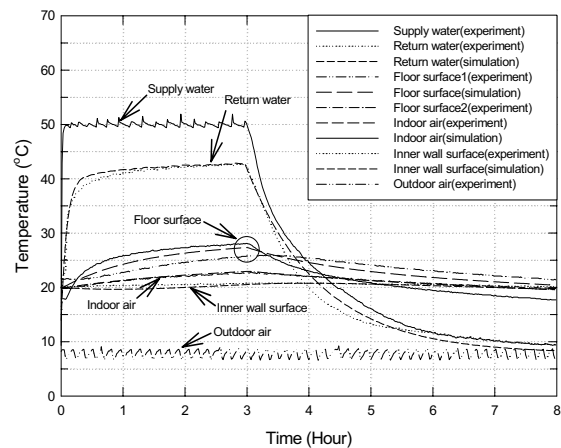
the wall and the floor are analyzed through various variables like outdoor air temperature, a supply flow rate and temperature, and has several operational features.

4. SIMULATION TESTING

A comparative study between results of test and simulation is made to investigated the simulation for the automatic thermostatic valve at the variable temperatures, flow rates such as supply hot-water, and outdoor air temperature. Figure 4 shows the test results and the simulation ones at different flow rates.



(a) $T_s=50^{\circ}\text{C}$, Flow rate=2lpm, $T_o=8^{\circ}\text{C}$



b) $T_s=50^{\circ}\text{C}$, Flow rate=3lpm, $T_o=8^{\circ}\text{C}$

Figure 4: Comparison of simulation and experiments

5. SIMULATION PROCESS

Proportional control and On-Off control, types of automatic thermostatic valve, each has classified according to sensing methods, water temperature sensing and air temperature sensing. They are performed by the tested simulation and define their features.

Each control of a flow rate and temperature has its own peculiarities as outdoor air is changing from -5°C to 5°C for 24hours. Table1 shows each control's characteristics.

Table 1: Classification of control methods.

Description	Explanation
Case1	No control method
Case2	Proportional valve control with air temperature feedback
Case3	Proportional valve control with water temperature feedback
Case4	On-off valve control with air temperature feedback

6. CONTROL ANALYSIS

Figure 5 shows results of changes in temperatures of return water, the floor and indoor air for 24hours. In case of the temperature, outdoor air is vibratory from -5°C to 5°C , return water rises up to 43.3°C from the specified point, and the floor and the indoor air rise up 20°C rapidly and then constantly to 32°C and 27.5°C . Each mean temperature of return water and indoor air is at 42.3°C and 24.9°C .

Figure 6 shows the changes of temperature and a flow rate for 24hours as a result of the proportional control for the indoor air temperature designated from 22.3°C to 23.3°C to maintain 22.8°C , the mean indoor temperature. The maximum flow rate helps adjust flow and maintain indoor air temperature of 23°C before reaching the lower limit, 22.3°C . Controlling flow can offset the change of outdoor air

temperature so that indoor air temperature can be maintained.

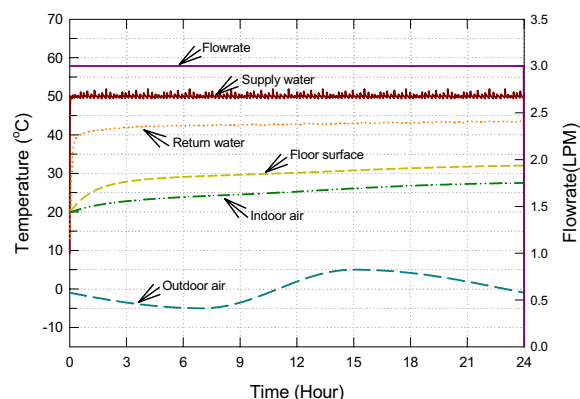


Figure 5: Various temperature changes (Case 1)

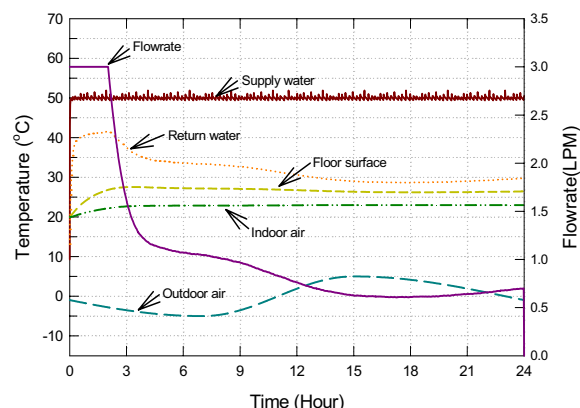


Figure 6: Various temperature changes (Case 2)

Except the first stage, the temperature of return water has a gentle slope, and that of floor surface is 27.9°C continuously. In this case, each mean temperature is 31.8°C , 22.8°C . This air-temperature proportional control maintains indoor temperature through light control regardless of the change of outdoor air temperature.

Figure 7 shows the changes of temperature and a flow rate for 24hours as a result of the proportional control for the return air temperature designated from 30.5°C to 34.5°C to maintain 22.8°C , the mean indoor temperature. Indoor air keeps up temperature of 33.1°C after rising up to 24.1°C initially. The flow rate steadily decreases but its drop dwindles except the

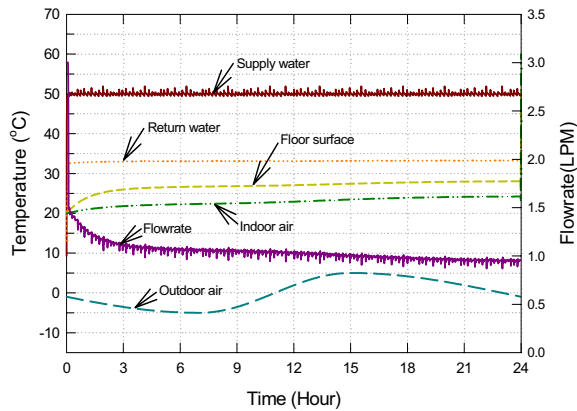


Figure 7: Various temperature changes (Case 3)

first stage. In this case, each mean temperature of the return water and indoor air is 33°C, 22.8°C.

Water proportional control doesn't cope with the change of indoor air temperature, but maintains return water temperature, and if indoor air temperature is the best condition it's hard to find the upper and lower limit that can maintain it.

Figure 8 shows the change of temperature and a flow rate for 24hours in flow-rate supply on – off at the range of indoor air temperature, 22.3°C to 23.5°C.

Primary indoor temperature of 20°C allows for long operation, and then 1 distance of On-Off makes it shorter. And the higher the outdoor air is, the longer the time period of operation is. The indoor temperature vibrates from 22.5°C to 23.5°C according to the control, and return water temperature is nearly similar to the floor surface when flow-rate supply is stopped. At this time each mean temperature of return water and indoor air is 34.4°C and 22.8°C.

In On-Off control, time difference of hot-water supply and non-supply happens in the change of outdoor air temperature, and indoor air temperature can affect the control. But the controls can't always maintain the indoor air temperate it's important to balance proper set point and a differential gap.

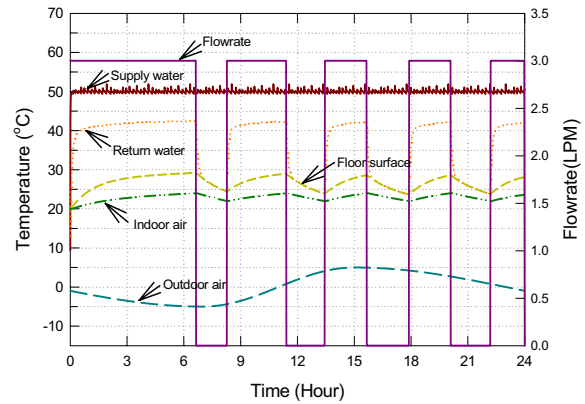


Figure 8: Various temperature changes (Case 4)

Figure 9 shows the mean temperature of room air and energy consumptions according to each control. No-Control(Case 1) is 2°C and 14,000Kcal higher than other controls(Case 2). And all controls, Case 2~4, have the similar the mean temperature but water temperature-sensing (Case 3) spends heat amount of 8% more than air temperature.

Figure 10 and 11 display the mean temperatures of room air and total amount of supply heat according to different controls changing the supply hot-water temperature of 40°C, 50°C, 60°C and 70°C.

Figure 10 demonstrates the mean temperature of room air per each control on the change of supply hot-water temperature. For No-Control (Case 1), the mean temperature is increasing in proportion to hot-water. However Control (Case 2~4) doesn't show the proportion. When hot-water is supplied, the ultimate temperature was 23.1°C in Case 1. It is not in this graph. For this reason, proportional control (Case 2) and On-Off (Case 4) based on indoor set temperature of 23°C are slightly different from Case 1. But water temperature proportional control (Case 3) has the mean temperature relatively lower than Case 1 due to control of the return water.

After that, at the supply hot-water of 50°C, 60°C and 70°C air temperature sensing method (Case 2, Case 4) keeps up

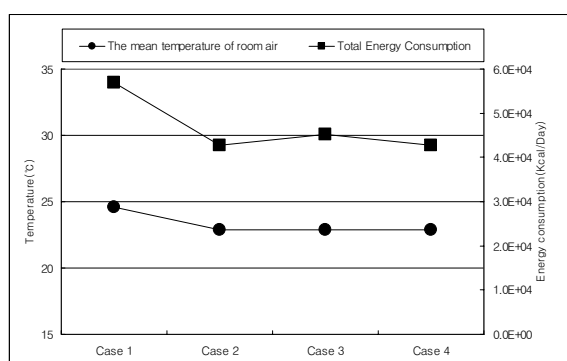


Figure 9: The mean temperature of room air and energy characteristics with different control methods.

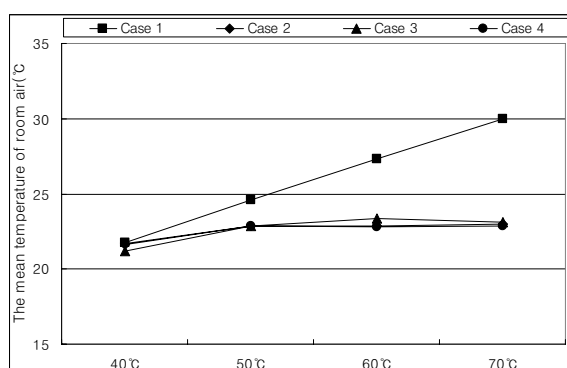


Figure 10: The mean temperature of room air with different supply water temperatures.

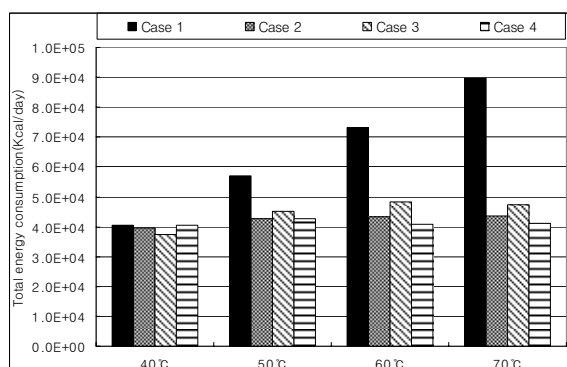


Figure 11: The energy characteristics with different supply water temperatures.

the mean temperature, and water temperature proportional control has a slight difference. This means supply hot-water temperature higher than 50 °C heat up the indoor mean temperature over 22.8 °C as water temperature proportional control (Case 3) deals with the return water temperature

for controlling the flow rate. In a case like this, it needs to readjust the set point. Rise from 60 to 70 makes the mean temperature come down. It's considered that earlier control for a flow rate may happen as supply hot-water temperature of 70 °C makes return temperature reach a set point faster than those of 60 °C.

As a result of total supply heat amount according to different supply hot-water temperature for each control, it makes a difference relative to increase in supply hot-water temperature for No-Control (Case 1), and it has no difference for air temperature sensing (Case 2) as shown figure 11.

And water temperature sensing proportional control (Case 3) is similar to the fluctuation of indoor air mean temperature in figure 10.

Air sensing On-Off control (Case 4) has unstable total supply heat amount, this is the difference of ultimate indoor air temperature because the change in supply hot-water temperature decides when On-Off happens. Both air temperature sensing (Case 2, Case 4) over hot-water supply temperature of 50 °C and water temperature sensing (Case 3) at 40 °C have less total supply heat.

The fact, which each control has a slight difference in total supply heat due to low heat supply as shown figure 10, is an energy characteristic at supply hot-water of 40 °C.

8. CONCLUSION

As a result of simulation analysis for control features and energy-saving abilities of air temperature sensing and water temperature sensing automatic thermostatic valve in the floor radiant heating system, this study reaches the following conclusions :

1) The simulation results follow the test data through heat analysis in the room applying a square simple model to an airtight space for energy analysis on equivalent R-C circuit, a lumped mass model, and radiant heat.

2) The room, that has an automatic thermostatic valve for the floor heating system, is 2°C lower than not has it. And at a point of comfort zone, it doesn't cause over-heating and so saves energy of 20~25%.

3) For the relatively low load, as compared to total supply heat along with different hot-water supply, water temperature sensing is energy-saving method, and if it's a large load on outdoor air and hot-water supply temperature, and supply flow rate, the air temperature sensing can cut the energy.

4) If supply hot-water's condition is changed after setting a basic point of automatic thermostatic valve, it's important to set the point fit for that. In case of the change of environmental conditions, air temperature sensing revises a set point with the feedback control, but water temperature sensing's feedback control is on the return water, there is, thus, needs to reset a point.

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