Heating Performance and Occupants' Comfort Sensation of Low temperature Radiant Floor Heating System in Apartment Buildings of Korea

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Abstract

To develop an energy-efficient low-temperature radiant floor heating system in an apartment housing unit from an improved the overall heating system efficiency perspective, it is essential to consider the occupants' thermal comfort and evaluate the thermal environment and thermal output of the radiant panel. This study evaluated the heating performance of a low temperature radiant floor heating system by monitoring the water flow rates, supply and return water temperatures, indoor room temperatures and floor surface temperatures through field measurements, and surveyed the occupants' thermal comfort through questionnaires. Based on the results of field measurements and the occupants' questionnaires, the heating performance and thermal comfort sensation of a low-temperature radiant floor heating system were analyzed. The design considerations of a low temperature radiant floor heating system are suggested.

Keywords: low temperature radiant floor heating system; heating performance; occupants' comfort sensation; field measurement; questionnaire

1. Introduction

Most Koreans live in residential buildings with a radiant floor heating system. Traditionally, Koreans used the exhaust smoke from a fireplace to heat a stone floor called 'ONDOL' in Korea. In the late 1970s, radiant floor heating panels using steel, copper pipes or plastic pipes, such as XL pipe, were installed above a concrete slab¹. Unfortunately, at this time, residential buildings were not well insulated so very high floor temperatures were needed to heat the space². Consequently, many Koreans became accustomed to hot floor surfaces. In addition, Koreans habitually sit on the floor, so their buttocks are almost in direct contact with a heated surface. Therefore, it is generally known that the range of comfortable floor temperatures for Koreans is higher than that of Europeans and Americans, and this unique comfort sensation is related to the energy consumption in modern apartment housing³. On the other hand, considering the current lifestyle of Koreans, the heating performance and occupants' comfort sensation should be evaluated first to apply a low-temperature radiant floor heating system to current apartment buildings in Korea. Also the Building Energy Efficiency Rating System has been in force since 2001 as an attempt to improve the energy efficiency of apartment complexes, which are the most common type of residence. Recent studies showed that the energy efficiency of apartment buildings has been enhanced by various advanced technologies such as the high performance insulation and window system⁴-⁶.

Therefore, this study evaluated the heating performance and occupants' comfort sensation through field measurements and a questionnaire in apartment buildings with a radiant floor heating system. For this purpose, the flow rates of supply water, supply and return water temperatures and the room thermal environment, such as indoor room temperatures and floor surface temperatures, was monitored through field measurements and also by a survey of the occupants' thermal comfort. Based on the results of a field measurement and occupant's questionnaire, the heating performance and thermal comfort sensation of the low-temperature radiant floor heating system were analyzed. This study investigated the heating performance and thermal responses of occupants with the low temperature radiant floor heating system in Korea. In addition, the design consideration of a low temperature radiant floor heating system was derived...
from an analysis of the heating performance and thermal comfort sensation.

2. Field Measurement

2.1 Construction of Apartment Buildings and Measurement Methods

In an analysis of the heating performance, an apartment complex with typical housing units in Korea was selected for field measurements, which is located at a latitude of 37.3° N. This is a 5-building apartment complex with one mechanical room, which includes 351 housing units. The heating and domestic hot water for each housing unit has been supplied to this apartment complex through the district heating network since 2003. Fig.1. shows the schematic diagram of heat distribution for heating and domestic hot water supply in an apartment building. For heating and domestic hot water supply, two heat exchangers in the mechanical room were used to adjust the supply water temperature below 60°C. Each housing unit contains four main rooms, such as the living room adjacent to the kitchen, master bedroom, bedroom 1, and bedroom 2. In considering the amendment history of building regulation about thermal insulation in Korea, the U-value of exterior wall, floor, roof, side wall, and window can be anticipated to be about 0.47, 0.35, 0.35, 3.84 W/m²K respectively. (Refer to Table 1.) In comparison with the current requirement of U-values, U-values of exterior wall, floor, roof, and window at that time have been strengthened about 74%, 52%, 61%, and 82% respectively. The total floor area of a housing unit is approximately 125 m². The balcony spaces adjacent to the outside air are placed in the north and south building envelope. Although the cantilevered concrete balcony is a building structure that extends outward away from a wall in an apartment building, the living floor space has been extended in some housing units by removing the balcony spaces after governmental permission for balcony remodeling since 2006. The structure of the radiant floor is the same as the commonly used radiant floor structure used for heating in Korea. As shown in Fig.2., the radiant floor structure consists of 10 mm insulation, 60 mm ALC (Autooclaved lightweight concrete), 40 mm cement mortar embedded with a XL pipe, and linoleum or wood material as a finishing layer above a 210 mm concrete slab. Thermal resistance over the pipe layer is about 0.084 m²K/W and thermal resistance under the pipe layer is about 0.877 m²K/W. The manifold, which is located at the center of the housing unit, was used for 8 separate pipe circuits with a similar pipe length. Every room was heated through two pipe circuits. Table 1. lists the pipe spacing, pipe diameter and pipe length of each pipe circuit.

The surface temperatures were firstly measured at the living room using a thermal video camera and infrared thermometer during the heating period and the overall surface temperature distribution was analyzed. To examine the heating performance of the low temperature radiant floor heating system, the flow rate of supply water and the supply and return water temperatures were measured during two months with one minute intervals at fifteen housing units of an apartment building (Jan. 1 – Feb. 28, 2013).

| Year of amendment | 1979 | 1980 | 1984 | 1987 | 2001 | 2010 | 2013 |
|-------------------|------|------|------|------|------|------|------|
| Exterior wall     | 1.05 | 0.58 | 0.58 | 0.58 | 0.47 | 0.36 | 0.27 |
| Floor             | 1.05 | 1.16 | 0.58 | 0.58 | 0.35 | 0.41 | 0.23 |
| Roof              | -    | 0.58 | 0.58 | 0.41 | 0.29 | 0.20 | 0.18 |
| Side wall         | -    | 0.47 | 0.47 | 0.35 | 0.27 | -    | -    |
| Window            | -    | 3.49 | 3.49 | 3.37 | 3.84 | 2.40 | 2.1  |

| Room | Pipe spacing (mm) | Pipe diameter (mm) | Pipe length of circuit (m) |
|------|-------------------|--------------------|---------------------------|
| Master | 230              | 15                 | 50                        |
| bed room   | 230              | 15                 | 50                        |
| Bed room | 230              | 15                 | 36                        |
| Bed room 2 | 230              | 15                 | 35                        |
| Living | 230              | 15                 | 41                        |
| room   | 250              | 15                 | 38                        |

Table 1. Amendment of Building Regulation Concerning Thermal Insulation in Korea. [W/m²K]

Table 2. Description of the Radiant Floor Panel at Each Room
To evaluate the room thermal environment of housing units, the room air temperatures and floor surface temperatures were also measured for ten days at one minute intervals at two housing units among the fifteen housing units (Jan. 9 – Jan. 18, 2013). To measure the room air temperature, wireless sensor modules were installed at the center of the living room, master bedroom and bedrooms 1 and 2. In addition, the PT 100 Ω sensors and a flow meter were mounted into the distribution manifold to measure the supply and return water temperature and water flow rate. The room thermostat was located at the center of the living room, and the desired room temperature was set easily by the dial gauge on the face of the thermostat. Therefore, the room thermal environment could be made according to the occupants’ desires. The set-point of the room thermostat could be changed according to the heating requirement of the occupants at each housing unit. Before the field measurement, the room air temperature was basically recommended to be set at 22°C by considering the general guidelines of the comfort range for the clothing level of 1.0 clo and activity level of 1.0 met in winter.

### 2.2 Results and Discussions

During operation of the radiant floor heating system, the general floor temperature distribution within seven housing units was evaluated using thermographic cameras set at an emissivity of 0.9 to measure the floor temperature of each living room from 10 AM to 12 PM on January 29, 2013. The outdoor air temperature during the measuring period was approximately 2.1–3.0°C. Table 3. lists the surface temperature measurements of the thermographic cameras. The surface floor temperatures showed substantial variations and were 20–30°C depending on the heating operation conditions. The temperature of the hot water supply was controlled using the outdoor reset control system in a mechanical room, floor surface temperatures will generally vary with the outdoor temperature. As the outdoor temperature decreases, the floor surface temperature must increase. Generally, the thermal output from the radiant floor heating system is determined by the water mass flow rate and the temperature differences between the supply and return temperature of the hydronic pipe circuits.

The heat rate supplied to a housing unit was analyzed to evaluate the current status of the heating performance of a low temperature radiant floor heating system. The water flow rate and temperature of the supply-return water for each housing unit were monitored over a 2-month period (Jan.1 – Feb.28, 2013). During the field measurement period, the outdoor air temperatures ranged from -17.9 °C to 14.3 °C, and the daily average outdoor air temperature ranged from -12.9 °C to 8.1 °C. Because the temperature of the hot water supply was controlled by the outdoor reset control method within the apartment complex, as shown in Fig.3.(a), the water supply was 40–45 °C when the daily average outdoor air temperature was below -5.0 °C and 40–45 °C when it was 0–5 °C. As Fig.3.(b) suggests, the specific heat supply rate during the heating operation is inversely proportional to the outdoor air conditions. In addition, the heating operation is controlled intermittently by the lifestyle of the housing unit occupants, even under the same outdoor air conditions when the heating operational hours were varied. The specific heat supply rate during the heating operation was approximately 20.0–30.0 W/m² when the daily average outdoor air temperature was below -3.0°C, and approximately 13.0–17.0 W/m² when the daily average outdoor air temperature was 0–5°C. As shown in Fig.3.(c), the supply water flow rate varied greatly between housing units (4–12 LPM) due to issues with the water flow to

| Housing units | Supply water temperature(°C) | Balcony space | Flooring | Floor surface temperature |
|---------------|-----------------------------|---------------|---------|--------------------------|
| Unit A        | 42.6                        | O             | Wood flooring | 26.4±1.24               |
| Unit B        | 41.3                        | X             | Carpet above the wood flooring | 23.3±1.69               |
| Unit C        | 44.0                        | O             | Carpet above the wood flooring | 26.9±1.64               |
| Unit D        | 42.3                        | X             | Wood flooring | 29.9±0.43               |
| Unit E        | Not supplied                | X             | Wood flooring | 25.8±0.99               |
| Unit F        | 42.1                        | O             | Wood flooring | 19.7±0.41               |

Table 3. Distribution of the Floor Surface Temperature at Each Housing Unit
each unit during the testing, adjusting and balancing (TAB) process prior to the heating operation. On average, a lower water flow rate to a housing unit meant a longer heating operation, and the hours of the heating operation increased with decreasing outdoor air temperature. Most housing units operated the heating continuously for 300–500 min on average during the entire heating operation period. As Fig.3.(e) suggests, the daily total heat energy supply was inversely proportional to the outdoor air temperature. The daily total supplied heat energy was 0.2–0.8 kWh/m²·d depending on the outdoor air conditions. With the exception of some housing units with child-care facilities, all measured housing units were supplied with approximately 0.4–0.5 kWh/m²·d of heating energy.

To evaluate the room thermal environment of the housing units, the room air temperatures and floor surface temperatures were measured for 10 days (Jan. 9–18, 2013) at 1-min intervals at two of the 15 housing units. For housing unit A, the room temperature was measured in each room (four points); for housing unit B, the room temperature was measured in each room (four points), and the floor temperature was measured at three points. The heating operation conditions for Jan. 15–17, 2013 were as follows (refer to Table 4. and Fig.4.). The daily average outdoor air temperature during the analysis period was -5.2 to -0.1°C; the room temperatures of housing unit A were 20 ± 2°C; and the room temperatures of housing unit B were 25 ± 5°C. Because each housing unit required a different degree of heating, the set-point temperature of the room air was different for each housing unit. The outdoor air conditions did not affect the set-point temperature of the room air of each housing unit. In the case of a large heating load due to the outdoor air temperature, the temperature of the heated water increased because of the outdoor reset control method in the mechanical room, or the hours of heating operation within the housing unit increased. This increased the floor surface temperature and supplied heat to the housing unit. The living room of each housing unit had a large window area with a high infiltration rate because it was connected to the doors of the entrance or balcony.

Thus, the air temperature remained lower than that of the other rooms. An analysis of the heating operation hours of the hot water supply for the three measurement days showed that to maintain the set-point temperature of the room air, housing unit A was supplied with hot water for a total of 490 min., which was approximately 11.3% of the total time. Housing unit B was supplied with hot water for a total of 1,018 min., which was approximately 23.6% of the total time. When the set-point temperature of room air was kept high, the heating operation hours increased if the hot water supply temperature was maintained.

The temperature differences between the supply and return water became smaller when the operation hours were increased. As Fig.4. (b) suggests, the average floor surface temperature was 28°C, which was 0.9–2.7°C higher than the average air temperature of the living room. The maximum floor surface temperature was approximately 30°C locally, which was slightly higher than the maximum floor temperature (29°C) as per ISO 7730. This shows that residents in Korea are used to slightly higher floor temperatures.

3. Questionnaire

3.1 Methods

A questionnaire-based survey was conducted to analyze the heating operation conditions and thermal comfort of the occupants in the housing units on the side of an apartment complex that had a low-temperature radiant floor heating system installed. The questionnaire included sections on the general information of the respondent and the degree of room air comfort, indoor thermal comfort and floor temperature comfort. To account for the family members of each residence, 60 sets of the questionnaire were distributed to the 15 housing units, and 27 sets (45.0%) were collected for the analysis. SPSS 12.0 was used for the analysis. SPSS (Statistical Package for the Social Sciences), which is currently the most widely
used statistical software, was used for data input and analysis. As shown in Fig. 5., crossing analysis was performed to compare the satisfaction with and without balcony expansion, the use of beds and sofas, room thermal comfort depending on the set-point temperature of room air, and subjective thermal sensation vote (TSV) on the room air and floor temperatures. The influential factors were tested for their significance through an Independent T-test and one-way Analysis of Variance (ANOVA); only those with significance were analyzed for their correlation with the factors that affected the thermal comfort of the occupants.

### 3.2 Results

Of the respondents, 33% were male and 67% were female. In terms of age, those in their 40s, 50s and over 60 comprised 19%, 37% and 26% of the respondents, respectively; these age groups made up 82% of all responses. Of the respondents, 26%, 4% and 63% were in their homes for 10–12, 12–14 and >14 hrs, respectively. Therefore, the housing units were occupied during the day and night, so heating was necessary. Most of the respondents appeared to be housewives in their 40s–50s or the elderly in their 60s, so they spent many hours in their housing unit. This is in contrast to students (below the age of 20) or people who had day jobs and were in their 20s–30s. Because females, elderly and weak occupants stayed longer in their housing units, an evaluation of the heating performance and improvement of the heating operation in future residences needs to consider the characteristics of these occupants. In addition, 67% of respondents spent most of their time in the living room. Therefore, the living room, which is the center space of the housing unit, is more important during the day than the bedroom. Approximately 44% of the housing units expanded the living room space to the balcony to secure more space. In addition, 93% used a bed in the bedroom, while 85% used a sofa in the living room. Although Koreans had a floor-based lifestyle in the past, this has now changed because more use furniture, such as beds and sofas in their housing units.

| Category                        | Housing unit A | Housing unit B |
|--------------------------------|----------------|----------------|
| **Outdoor air temperature (°C)** |                |                |
| Average                        | -5.0           | -5.0           |
| Maximum                        | -0.9           | 1.3            |
| Minimum                        | -11.6          | -9.0           |
| **Supply water temperature (°C)** | 45.9           | 46.1           |
| **Return water temperature (°C)** | 31.5           | 30.4           |
| **Room air temperature (°C)**  |                |                |
| Living room                    | 19.4           | 18.4           |
| Master bedroom                 | 20.7           | 21.2           |
| Bedroom 1                      | 19.9           | 19.5           |
| Bedroom 2                      | 19.7           | 19.2           |
| **Floor surface temperature (°C)** |                |                |
| Average                        | -27.6          | 27.8           |
| Maximum                        | -29.4          | 30.0           |
| Minimum                        | -22.8          | 25.2           |
Of the respondents, 73% felt that the floor surface temperature of the master bedroom was cold, so the heating performance requires improvement. Unlike the past, these results suggest that the effective floor area for heating has been reduced substantially because most housing units use a bed in the master bedroom. For the apartment complex evaluated, the pipe length within the master bedroom was rather long, which may have caused a heating imbalance in the rooms. The occupants felt that the floors of bedroom 1 and the kitchen were warmer; these rooms were close to the manifolds, so the pipe length was shorter than that of the other rooms and the friction loss of the pipe pressure was lower than that in the pipe circuits of the other rooms, resulting in a higher water flow rate. Of the respondents, 15%, 4%, 42%, and 39% set the room air temperature during heating operation to below 18, 20, 22, and 24°C, respectively. Therefore, the heating rate varied depending on the occupant's preference. In the early phase of the experiment, it was recommended that the occupants set the room air temperature to 22°C during the heating operation, but most set the temperature to above 22°C. This suggests that the occupants using the low-temperature radiant floor heating system in Korea have a high thermal comfort level. The occupants showed an approximately 43% degree of satisfaction with the thermal environment; 92% of the respondents wanted their residences to be warmer in general. Furthermore, 41% of the occupants felt comfortable, whereas 59% felt slight discomfort. In response to questions on the thermal sensation vote (TSV), 85% and 70% responded that they felt the room air temperature and floor surface temperature, respectively, to be slightly chilly.

As shown in Table 5., of the respondents satisfied with the current room environment, 10.0% had expanded balconies, whereas 90% did not. Of the respondents dissatisfied with the current room environment, 61.5% had expanded balconies, whereas 38.5% did not. The satisfaction with the current room environment was tested for significance through a T-test. As shown in Table 6., the occupants of housing units without a balcony expansion were satisfied with the room environment, i.e., the result was significant. As shown in Table 7., the occupants of housing units without a sofa had a low set point. As shown in Tables 11. and 12., with regard to the floor temperature suitability during the heating operation, 4.3% answered that it was cold, 26.1% answered that it was chilly, 65.2% answered that it was slightly chilly, and 4.3% answered that it was suitable. All the respondents without a sofa answered that it was slightly chilly, which suggests that the occupants with a sofa felt the floor temperature to be colder.

### Table 5. Cross Analysis of the Overall Satisfaction of the Thermal Environment According to Balcony Remodeling

| Category                  | Overall satisfaction of thermal environment |
|---------------------------|---------------------------------------------|
|                           | Satisfied (%) | Not satisfied (%) | Total (%) |
| Balcony remodeling        |               |                 |           |
| Yes                       | 10.0          | 61.5            | 39.1      |
| No                        | 9.0           | 38.5            | 47.0      |
| Total                     | 100.0         | 100.0           | 100.0     |

* Assumption: Balcony remodeling = 1, No balcony remodeling = 2

### Table 6. Significance Test of the Overall Satisfaction of the Thermal Environment Due to Balcony Remodeling

| Overall Satisfaction of Thermal Environment | Balcony remodeling | T-value* |
|---------------------------------------------|-------------------|---------|
| No                                          |                   |         |
| Yes                                         |                   |         |
| Satisfied                                   | 10                | 1.9     | 0.32    | 2.816 |
| Not satisfied                               | 13                | 1.38    | 0.51    |       |

* Assumption: Balcony remodeling = 1, No balcony remodeling = 2

### Table 7. Cross Analysis of the Set Point of the Room Air Temperature According to Gender

| Category                  | Below 18°C (%)  | 20°C (%) | 22°C (%) | Above 24°C (%) | Total (%) |
|---------------------------|-----------------|----------|----------|----------------|-----------|
| Gender                    |                 |          |          |                |           |
| Male                      | 75.0            | 100.0    | 45.5     | 0.0            | 34.6      |
| Female                    | 25.0            | 0.0      | 54.5     | 100.0          | 65.4      |
| Total                     | 100.0           | 100.0    | 100.0    | 100.0          | 100.0     |

### Table 8. Significance Test of the Set Point of the Room Air Temperature According to Gender

| Set-point of room air temp. | No. | Gender | F*  |
|-----------------------------|-----|--------|-----|
| Below 18°C                  | 4   | 1.25   | 0.50|
| 20°C                        | 1   | 1.00   | -   |
| 22°C                        | 11  | 1.55   | 0.52|
| Above 24°C                  | 10  | 2.0    | 0.0 |

* Assumption: Male = 1, Female = 2
Table 9. Cross Analysis of Lifestyle Using a Sofa in the Living Room According to the Set Point of the Room Air Temperature

| Category of Room Air Temperature | Using a Sofa |
|---------------------------------|-------------|
| Below 18°C                      | 18.2        |
| 20°C                            | 4.5         |
| Above 24°C                      | 50.0        |
| Total                           | 100         |

Table 10. Significance Test of the Set-Point of Room Air Temperature Due to Lifestyle Using a Sofa in the Living Room

| Using Sofa | Set point of room air temp. | T-value* |
|------------|-----------------------------|----------|
| Yes        | 23, 72°C                    | 1.04     |
| No         | 24°C                        | 0        |

Table 11. Cross Analysis of Lifestyle Using a Sofa in the Living Room According to the Thermal Sensation Vote of the Floor Surface Temperature

| TSV of Floor Surface Temp. | Using Sofa |
|----------------------------|-----------|
| Cold                       | 4.3       |
| Cool                       | 26.1      |
| Slightly Cool              | 65.2      |
| Neutral                    | 4.3       |
| Total                      | 100       |

Table 12. Significance Test of the Thermal Sensation Vote of Floor Surface Temperature Due to Lifestyle Using a Sofa in the Living Room

| TSV of Floor Surface Temp. | Using Sofa |
|----------------------------|-----------|
| Yes                        | 26.9      |
| No                         | 3.00      |

4. Discussions Concerning the Design Consideration

The building technologies of late are focused on energy efficiency and potential savings by reducing the emission of greenhouse gases. In addition, the energy policy gives high priority to building energy savings and the use of renewable energy. In European Countries, ambitious targets have been set to ensure that all new buildings consume very little energy and have created the term "nearly Zero-Energy Building (nZEB)" from 2020. In Korea, the government announced that all new buildings must have high performance insulation and high performance windows have all contributed to reducing building energy use, which provides lower heat transmission and infiltration losses in buildings. In particular, heating energy can be saved using a low-temperature radiant floor heating system. Because the efficiency of boiler is correlated directly with the maximum supply water temperature, the low temperature heating system can be more energy efficient during the production of heating energy. The boiler's efficiency improves with the decreasing supply temperature of water. Furthermore, the entire processes of heat distribution can be performed with lower energy losses. In this case, the heating energy losses, i.e., the dissipation of heating energy decreases with decreasing temperature of the heating fluid.

With regard to the application of a low temperature radiant floor heating system in apartments in Korea, thermal comfort can be influenced by floor surface temperature and associated parameters, such as radiant asymmetry, MRT (mean radiant temperature) and OT (operative temperature). As the room thermal environment can be changed due to a reduction of the heating load in low-energy apartment buildings, the local thermal discomfort, such as floor surface temperatures and vertical air temperature differences should be considered during heating system design. When energy regulation in buildings is considered, the floor surface temperature can be lowered to 29°C. Koreans sat or laid down on the floor in the past, so the temperature of both the floor surface and room air were important factors during the design of radiant floor heating systems in residential buildings. Generally Koreans have been accustomed to sitting on the floor, and some Korean research on the comfort shows that the buttocks skin temperature is a reliable index in evaluating the thermal comfort of a person in a sedentary posture. Recent research on the Korean human response to floor surface temperature and resident's posture change shows that the comfortable temperature range of a plantar surface was 35.1-38.9°C and the buttock surface 37.8-39.3°C. According to the TSV in accordance with the floor surface temperature, residents feel slightly chilly at a 25°C and 30°C floor surface temperature in a standing posture and chilly at a 25°C and neutral at a 30°C floor surface temperature in a sitting posture. In this study, we prepared a questionnaire with choices concerning the thermal sensation vote of floor surface temperature: Cold, Cool, Slightly Cool and Neutral. Although this can lead to choosing a negative answer in other countries, most Korean residents' TSV can be slightly cool shown in Ch.3. However, because the floor surface temperature depends on the thermal characteristics of the covering materials, it is necessary to consider the floor surface characteristics. Generally, the higher the thermal resistance, the lesser the temperature fluctuation. A warm floor surface temperature of around 29°C can serve to satisfy Korean occupants when the...
room temperature is maintained at around 22°C which represents an energy conscious temperature. According to the previous research, a warm floor can induce high blood perfusion in the feet and consequently improve an occupant's health by treating many vascular-related disorders. Even in a well-insulated apartment building with low-temperature radiant floor heating system, a partially heated floor system could prevent overheating while providing surface warmth. Currently, the lifestyle of Koreans has changed through the use of sofas in the living room, so the comfortable floor surface temperature in the living room can be lowered to around 29°C, which is the recommended maximum surface temperature of radiant floor heating systems in ISO 7730.

In considering that the thermal comfort and energy efficiency of the low temperature radiant floor heating system depends on the heat transmission to the floor finishing surface from the pipe layer, dynamic heat transfer characteristics such as thermal conductivity and heat capacity should be improved especially for wood finishing. In the case of wood finishing, the floor thickness and installation methods affect heat transfer from the heat storage layer.

As it is shown that the heating performance of the radiant floor heating system is affected by a decrease in the effective floor area for heating because most Koreans use a bed in the bedroom, and a sofa in the living room, we need to consider the partial radiant floor heating in places without furniture. Owing to balcony expansion, thermal discomfort caused by the radiant asymmetry from the exterior wall and windows occurred. We need to consider the enhancement of heat emission from the radiant floor to prevent the thermal discomfort problem.

5. Conclusions

This study evaluated the heating performance and occupants' comfort sensation through field measurements and a questionnaire in recently built apartment buildings with a low temperature radiant floor heating system. Recently, the lifestyle of most Koreans has changed to a more western style. As most Koreans use a bed in the bedroom, and a sofa in the living room, the heating performance of the radiant floor heating system is affected by a decrease in the effective floor area for heating. So we need to consider partial radiant floor heating in places without furniture. Owing to balcony expansion, thermal discomfort caused by the radiant asymmetry from the exterior wall and windows occurred. Therefore we need to consider the enhancement of heat emission from the radiant floor to prevent the thermal discomfort problem. In addition, when energy regulation in buildings is considered, the floor surface temperature can be lowered to around 29°C when the room temperature is maintained at around 22°C.

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