An Evaluation of Apartment Heating System for Energy-Saving

Sung Jo Park[1], Byung Do Choi[1], Jung Ha Park[1] and Jin Chul Park*[2]

[1] Graduate School, School of Architecture and Building Science, Chung-Ang University, Korea
[2] Professor, School of Architecture and Building Science, Chung-Ang University, Korea

Abstract

This study conducted a comparative analysis of types of apartment heating systems by considering energy consumption amount through a simulation, and the results can be summarized as follows; in the simulation of three apartment heating systems, which were floor radiation, capillary radiation, and EHP, when applying 1st (within 5 years, case 2, 30%) and 2nd (within 10 years, case 3, 50%) energy reduction goals, case 3 (after 10 years) of EHP system was found to achieve a reduction in energy consumption of 25% compared with the floor radiation system, and of 35% compared with the capillary radiation system. These research findings will enable energy savings by changing apartment-heating systems from being fully dependent on the current floor radiation heating and combining with EHP.

Keywords: apartment heating (radiant, convection & capillary radiation) system; energy-saving strategies; TRNSYS

1. Introduction

According to domestic statistical data (KOSIS, 2010), apartment housing accounts for the highest percentage (75.6%) of all residences. Furthermore, heating energy accounts for 74.9% of all energy consumption in residential buildings (KEEI, 2010). Therefore, to achieve overall energy savings, it is necessary to consider ways of reducing the heating energy used in apartments.

The Korean government intends to reduce the energy used in buildings by 30% as a first-stage goal (within 5 years) and by 60% as a second-stage goal (within 10 years). Therefore, this study conducted a comparative analysis of types of apartment heating systems by considering the amount of energy consumption through a simulation. The data will be used as fundamental material to develop and select new heating systems for future apartments.

Details of the research conducted in the study are as follows:

1) Through theoretical consideration, the previous research related to apartment heating systems was investigated and analyzed.

2) An apartment energy-reduction goal was set, and applicable heating systems were selected.

3) Through simulations, energy performance was evaluated according to the type of apartment heating system.

2. Theoretical Consideration

Recent studies of room heating systems in domestic/overseas residential buildings have been mainly conducted for floor radiation heating.

First, among domestic studies, Lee *et al*. (2002) evaluated load change and adaptability of prediction control of heat characteristics through an active simulation to improve the control performance of floor radiation in apartments. Jeong *et al*. (2010) conducted a comparative analysis on existing convection heating systems and ceiling radiation-heating systems through actual measurement. Kim *et al*. (2011) conducted a comparative analysis on heating methods through a simulation to propose an apartment heating system as a change of lifestyle. Kim *et al*. (2012), who considered three heating systems (floor radiation, convection, and a combination of floor radiation and convection), conducted a comparative analysis on room temperature distribution and energy consumption according to heating methods through a mock-up test and CFD simulation to improve apartment heating methods.

Meanwhile, in foreign countries, Miura *et al*. (2003) proposed measures to improve heating systems by investigating heat loss in the warm-water bottom heating system of residential houses. Yee *et al*. (2005) proposed a dry floor heating system using heating pipes and evaluated this system through a pilot test. Asada and Boelman (2004) analyzed energy of a low-temperature radiation heating system through a dynamic simulation model. Miura *et al*. (2004) developed an applied system

*Contact Author: Jin Chul Park, Professor
School of Architecture and Building Science,
Chung-Ang University, Heukseok-ro 84, Dongjak-gu, Seoul, Korea
Tel: +82-2-820-5261 Fax:+82-2-812-4150
E-mail: jincpark@cau.ac.kr
(Received April 14, 2013 ; accepted March 7, 2014)

in three stages to evaluate thermal performance of a floor heating system and used this method to analyze the thermal characteristics of floors.

When comprehensively considering the results of this study, it can be seen that, currently, the performance of room heating systems has been evaluated through thermal performance and energy consumption. However, studies on the evaluation of the performance of room heating systems in residential buildings in relation to energy saving in the future are insufficient.

3. Set Apartment Energy-Reduction Goal and Select Heating System

3.1 Set Energy Reduction Goal

The study, as shown in Table 1., set 5- and 10-year future energy-reduction goals vs. the present in apartments. That is, for the energy-reduction goal, 5 years beyond the present was set as 30% lower, and 10 years beyond the present was set as 60%. At that time, selected energy-performance standards were elements of adiabatic values of outer walls and windows, ventilation rate, thermal transfer exchange amount, etc.

Table 1. Three Steps of Energy-Saving Building in the Future

Section		Step 1 (Present)	Step 2 (5 years later)	Step 3 (10 years later)
Energy-consumption reduction vs. current energy consumption		0%	30%	60%
Performance standard	Adiabatic value of outer walls [$W/m^2 \cdot K$]	0.47	0.36	0.20
	Adiabatic value of windows [$W/m^2 \cdot K$]	3.00	2.10	1.50
	Ventilation rate	0.7ACH	0.5ACH	0.5ACH
	Thermal transfer exchange amount	30%	60%	75%

3.2 Select Heating System

For heating systems applicable to domestic apartments, floor radiation heating, capillary radiation heating, electric heat pump (EHP), package terminal air conditioner (PTAC), and fan coil unit (FCU) systems were selected and analyzed.

(1) Floor radiation heating system

The floor radiation heating system is the most general and representative heating system in Korea, with the highest indoor comfort sensation and the advantage of accumulated technical knowledge.

(2) Capillary radiation heating system

The capillary radiation heating system was developed from the floor radiation heating system and has the advantages of highly comfortable sensation and a rapid response time. However, there is a problem developing a boiler volume appropriate for the capillary radiation heating system.

(3) EHP

The EHP has the advantages of a short preheating time and good controllability. Especially considering that the Korean lifestyle is changing from a sitting culture to standing culture, the EHP was analyzed as a method with very high future applicability. Specifically, because air-conditioning is now required, it is a system that provides the advantage of being able to both cool and heat.

(4) PTAC

The PTAC is a system applied selectively for cooling at current residential spaces. The system has the advantage of easy installation but is disadvantageous in terms of energy saving because of its high electrical load. Also, it has a slow response speed and is disadvantageous for centralized cooling and heating applications.

(5) FCU

The FCU can be used for both cooling and heating and has an advantage of flexibility at load change. Because of its disadvantages in terms of response speed and the high amount of indoor noise it produces, it is hard to apply to residential buildings.

Therefore, after analyzing the characteristics of each system, three systems—floor radiation heating, capillary radiation heating, and EHP—were deemed applicable to the apartment heating system for an energy-reduction study.

4. Simulation According to Heating System

For the simulation of energy-performance analysis according to types of apartment heating systems, TRNSYS (V.17.1) was used.

4.1 Overview and Building Modeling

In 2012, the simulation was applied to buildings in Seoul that were household types with $84m^2$ of common-area use (KMG, 2012). For the simulation, each had four residents.

Household location of the simulation was set at the middle floor, as opposed to the top- or bottommost floors. Households other than the target were blocked in general under the same set temperature to create conditions similar to the actual conditions for the target household in relation to the outer environment (see Figs.1. and 2.).

4.2 Simulation Boundary Values

According to the stages of the apartment energy-reduction goal set above, the study set the simulation boundary values shown in Table 2.

In addition, schedules of occupants were applied by investigating the number of occupants in each time slot of weekdays, weekends, and holidays in 30 of 1,700 total households (see Fig.3.).

Seoul was the area of the target building for simulation, and the climate data used were the standard

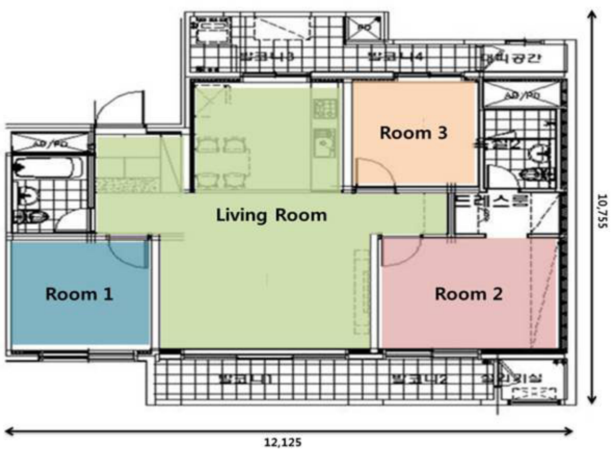

Fig.1. 84-m² Floor Plan

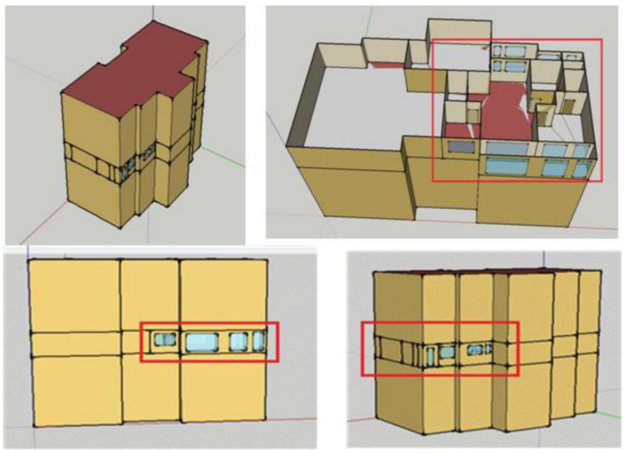

Fig.2. Middle-Floor Households

Table 2. Boundary Values According to Energy-Reduction Goal

Section	Case 1 (Present; base model)	Case 2 (5 years later; energy-saving model 1)	Case 3 (10 years later; energy-saving model 2)
Energy consump-tion	100%	70%	40%
Heating load reduction [%]	-	36.0	86.0
Structure insulation condition	Use adiabatic value based on energy-reduction design standard.	Apply adiabatic value that can use 30% less energy than the base model.	Adjust adiabatic value that can use 60% less energy than the base model.
Light	Input indoor consumption power 19 W/m².		
device	Use two computers, a television, and a drier. Input by converting to 230-W computer use.		

climate data of Seoul. At that time, 22°C was applied as the heating setup temperature, and heating periods were January, February, March, October, November, and December. The set values of each heating system applied to the simulation are shown in Tables 3. to 5.

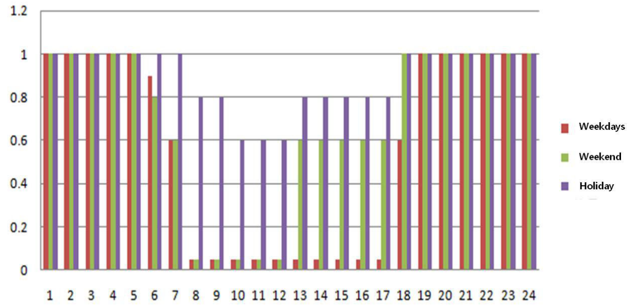

Fig.3. Residents' Schedule

Figs.4. and 5. show each heating system embodied in simulations that applied set values of heating systems.

As for boilers of the floor radiation and capillary radiation heating systems, those with 85% efficiency that were generally used for apartment houses (84 m²) were applied. Each EHP heating system was composed using COP values according to air and indoor temperatures. In particular, coil interval, external diameter, and hot-water supply temperature were set using the Design Graph for Capillary Radiation Panels (ASHRE 2012).

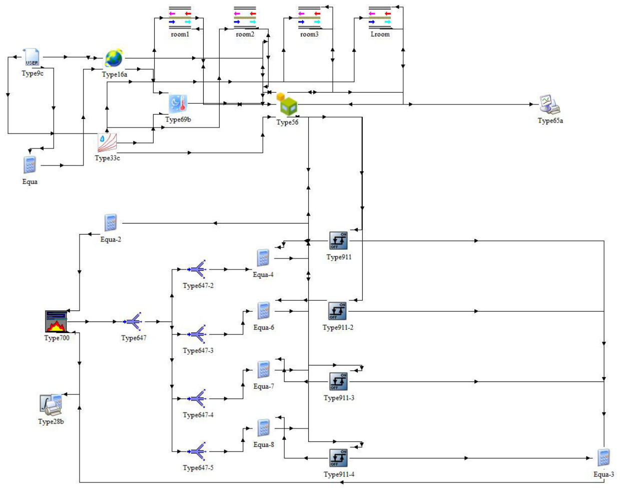

Fig.4. Floor and Capillary Radiation Heating System Components

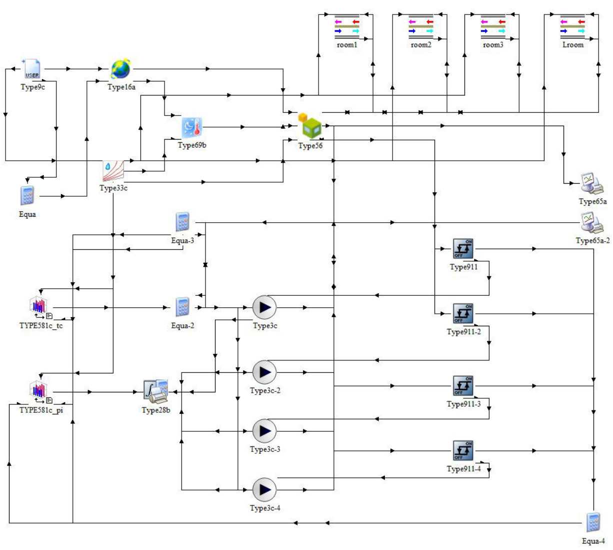

Fig.5. EHP Heating System Components

Table 3. Values Applied to the Floor Radiation Heating System

Applications	Boiler: General boiler efficiency corresponding to 84 m^2 (85%) Hot-water coil interval: 0.2 m External diameter of hot-water coil: 0.02 m
System operation setup	· By producing hot water at the boiler, hot water is provided to each room's coil through the hot-water distributor. · When each room's temperature reaches the set temperature, cease supply through the controller of each room; when all rooms are finished, boiler operation is finished as well.
Module type in TRANSYS	· As a floor radiation heating system, a type 700 (TESS Libraries) provided by TRANSYS was used. · In the case of building modeling, Type 56 was used.

Table 4. Values Applied to the Capillary Radiation Heating System

Applications	Boiler: Floor radiation corresponding to 84 m^2 Boiler volume application (efficiency 85%) Hot-water coil interval: 0.016 m External diameter of hot-water coil: 0.005 m (ASHRAE, 2012)
System operation setup	· By producing hot water at the boiler, hot water is provided to each room's coil through the hot-water distributor. · When each room's temperature reaches the set temperature, cease supply through the controller of each room; when all rooms are finished, boiler operation is finished as well.
Module type in TRANSYS	·As a Capillary radiation heating system, a type 700 (TESS Libraries) provided by TRANSYS was used. · To apply the Capillary radiation heating system, the coil pipe diameter (0.005 m) and spaces (0.016 m) were adjusted through changes of the Active Layer in the TRN Build.

Table 5. Values Applied to the EHP Heating System

Applications	EHP: DNM-mini (4 HP) Fan: One-way method
System operation setup	· Set the COP and indoor discharge temperature according to the outdoor and indoor temperatures at the EHP. · By connecting the fan at each room, operate it until reaching the set temperature. · When each room's temperature reaches the set temperature, fan operation of the relevant room is ceased; when all fans are ceased, the EHP is ceased as well.
Module type in TRANSYS	· To model the performance of EHP, a multi dimensional data interpolation Type 581c was used. · In the case of the capacity (T581c EHP_c_ TC, TC: total capacity), two independent variables, one dependent variable (capacity), 19 outdoor temperature T_o data, and 7 indoor temperature T_i were used.

4.3 Simulation Results

In the simulation results for the floor radiation heating system, the amount of energy use was 189.36 kWh/m^2·yr in case 1, 135.55 kWh/m^2·yr in case 2, and 33.94 kWh/m^2·yr in case 3. Therefore, energy reductions of 28.4% and 82.1% for case 2 and case 3, respectively, were achieved compared with case 1 (see Table 6.).

Table 6. Simulation Results for the Floor Radiation Heating System

Section		Case 1	Case 2	Case 3
Energy consumption [kWh]	January	3,731	2,911	995
	February	2,947	2,162	592
	March	2,013	1,306	123
	October	268	95	-
	November	2,278	1,542	264
	December	3,223	2,335	617
	Sum	14,460	10,351	2,592
Yearly sum (1st energy) [kWh/m^2·yr]		189.36	135.55	33.94
Energy reduction [%]		-	28.4	82.1

Table 7. Simulation Results for the EHP Heating System

Section		Case 1	Case 2	Case 3
Energy consumption [kWh]	January	1,332	996	278
	February	977	712	118
	March	493	288	-
	October	10	-	-
	November	589	359	27
	December	1,096	727	118
	Sum	4,497	3,082	541
Yearly sum (1st energy) [kWh/m^2·yr]		147.21	100.90	17.73
Energy reduction [%]		-	31.5	88.0

Table 8. Simulation Results for the Capillary Radiation Heating System

Section		Case 1	Case 2	Case 3
Energy consumption [kWh]	January	5,326	3,698	1,197
	February	4,016	2,918	642
	March	2,586	1,686	82
	October	251	57	-
	November	3,050	2,006	267
	December	4,436	3,097	649
	Sum	19,648	13,462	2,836
Yearly sum (1st energy) [kWh/m^2·yr]		257.51	176.28	37.17
Energy reduction [%]		-	31.5	85.6

In the simulation results for the EHP heating system, the amount of energy use was 147.21 kWh/m^2·yr in case 1, 100.90 kWh/m^2·yr in case 2, and 17.73 kWh/m^2·yr in case 3. Therefore, energy reductions of 31.5% and 88.0% for case 2 and case 3, respectively, were achieved compared with case 1 (see Table 7.).

In the simulation results for the capillary radiation heating system, the amount of energy use was 257.51 kWh/m^2·yr in case 1, 176.28 kWh/m^2·yr in case 2, and 37.17 kWh/m^2·yr in case 3. Therefore, energy reductions of 31.5% and 85.6% for case 2 and case 3, respectively, were achieved compared with case 1 (see Table 8.).

4.4 Comprehensive Analysis of Simulation Results

Simulation results are organized in Table 9. and Fig.6.

Table 9. Energy Simulation Results

Section		Case 1	Case 2	Case 3
Energy consumption [kWh/m^2·yr]	Floor radiation heating	189.36	135.55	33.94
	EHP heating	147.21	100.90	17.73
	Capillary radiation heating	257.51	176.28	37.17

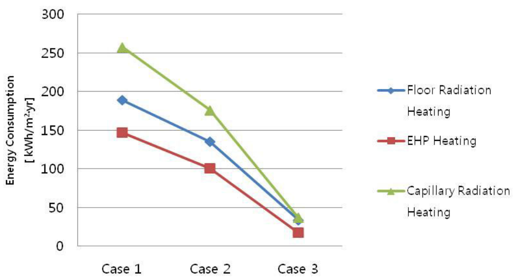

Fig.6. Energy Simulation Result Graph

That is, in the results of a simulation according to the heating system type (floor radiation, EHP, capillary radiation), the EHP heating system in case 2 (5 years later) showed 25% and 42% lower energy use compared with the floor radiation and capillary radiation heating systems, respectively. The EHP heating system in case 3 (10 years later) showed 47% and 52% lower energy use compared with the floor radiation and capillary radiation heating systems, respectively. Also, if the EHP heating system's volume is reduced it is expected to save additional energy.

In addition, high sealing and insulation of buildings according to the stages of energy reduction decreased differences in amounts of energy use among the different heating systems.

Meanwhile, capillary heating increased the amount of energy use because of increased hot-water flux compared with floor radiation heating. If a boiler for capillary radiation heating is developed, the capillary system is also expected to save energy.

5. Conclusions

A comparative analysis of three apartment-heating systems—floor radiation, capillary radiation, and EHP—was conducted through simulation of energy consumption, and the results are summarized as follows.

When applying first-stage (within 5 years, case 2, 30%) and second-stage (within 10 years, case 3, 60%) energy-reduction goals, the EHP heating system in case 2 (5 years later) reduced the amount of energy use by about 25% and 42% compared with the floor radiation and capillary radiation heating systems, respectively. The EHP heating system in case 3 (10 years later) reduced the amount of energy use by about 47% and 52% compared with the floor radiation and capillary radiation heating systems, respectively.

In addition, as the energy-reduction stages proceeded, the differences in the amount of energy use among the different heating systems decreased.

Therefore, according to the study results, the highest energy reduction was achieved by escaping from full dependence on floor radiation heating and combining with the EHP heating system.

Acknowledgments

This research was supported by the Chung-Ang University Excellent Student Scholarship.

References

1) Asada, H. and Boelman, B. (2004) Energy analysis of a low temperature radiant heating system. Building Services Engineering and Research Technology, 25 (3), pp.197-209.
2) ASHRAE. (2012) A source of information. In: ASHRAE. 2012. ASHRAE Handbook—HVAC Systems and Equipment (SI) Ch. p.6.
3) Baek, J., Choi, J., Jang, S. Y. and Park, M. (2010) Simulational analysis of adaptive outdoor reset control based on a fuzzy target temperature gap for a hydronic radiant floor heating system. Journal of Asian Architecture and Building Engineering, 9 (1), pp.251-257.
4) Miura, H., Hokoi, S., Nakahara, N. and Huang, Y. (2003) Heat loss from hot water floor heating system to crawl space: Field survey and improvement of energy consumption. Journal of Asian Architecture and Building Engineering, 2 (1), pp.33-40.
5) Miura, H., Hokoi, S. and Kondo, S. (2004) Development of simple commissioning tools for floor heating systems in residences: Performance evaluation of floor heating systems. Journal of Asian Architecture and Building Engineering, 3 (1), pp.93-100.
6) Jeong, Y. M., Yang, H. S., Lee, G. T., Yoo, S. H. and Sohn, J. Y. (2010) Thermal environment evaluation through application of radiant heating ceiling system, Proceedings 2010 AIK Autumn Annual Conference CJU, Chonhju, 1, pp.415-416.
7) Kim, J. W., Seo, S. M., Kim, Y. H., Cho, S. K. and Park, J. C. (2011) A study on thermal environmental and energy consumption by using convective and radiant heating, Proceedings 2011 SAREK Summer Conference Yong Pyong Resort, Gangwon-do, 1, pp.124-127.
8) Kim, S. D., Kim, J. W., Kim, D. Y., Lee, K. H. and Park, J. C. (2012) A study on the improvement of heating system through experiment and simulation in apartment house. Architectural Institute of Korea Journal, 28 (7), pp.253-260.
9) Korea Energy Economics Institute. (2011) Energy Consumption Survey 2011, Gveonggi-do: Korea Energy Economics Institute.

10) KOSIS. (2010) Population and housing census. [online] Available at: <http://kosis.kr/abroad/abroad_01List.jsp#jsClick> [Accessed 25 March 2013].
11) Kunping, L. and Yinping, Z. (2003) The performance of underfloor electric heating system with latent thermal storage. Journal of Asian Architecture and Building Engineering, 2 (2), b49-b53.
12) Lee, J. Y., Yeo, M. S. and Kim, K. W. (2002) Predictive control of the radiant floor heating system in apartment buildings. Journal of Asian Architecture and Building Engineering, 1 (1), pp.105-112.
13) Roh, H. and Udagawa, M. (2004) Simulation study on solar house with floor and hot water heating system. Journal of Asian Architecture and Building Engineering, 3 (2), pp.239-246.
14) Seoul Metropolitan Government. (2012) Seoul Statistical Yearbook. 52nd ed. (51-6110000-000003-10) Seoul: Information Open Policy Division.
15) Xindong, W., Ji, X., Jun, J., Weijun G., Bill, B. and Toru, M. (2006) Prediction of residential building energy consumption in Jilin Province, China. Journal of Asian Architecture and Building Engineering, 5 (2), 407-412.
16) Yee, J. J., Kim, Y. K. and Choi, S. Y. (2005) A performance evaluation on the prefabricated floor heating system using thermo siphon type heat pipe. Architectural Institute of Korea Journal, 21 (3), pp.173-180.