An Energy Saving Technique Using Ondol Heating Schedule Control of Housing Units in Korea

Sunkuk Kim, Donghoon Lee and Hiki Hong

Indoor and Built Environment 2010 19: 88
DOI: 10.1177/1420326X09358033

Original Paper

Indoor and Built Environment

Indoor Built Environ 2010;19;1:88–93

Accepted: October 30, 2009

An Energy Saving Technique Using Ondol Heating Schedule Control of Housing Units in Korea

Sunkuk Kim[a] Donghoon Lee[a] Hiki Hong[b]

[a]Department of Architectural Engineering, Kyung Hee University, Yongin 446-701, Korea
[b]Department of Mechanical Engineering, Kyung Hee University, Yongin 446-701, Korea

Key Words
Ondol · Heating · Schedule control · Energy saving · CO_2 reduction

Abstract
This study was performed to determine the heating energy savings and carbon dioxide reduction that would result from turning off ondol heating in housing units in Korea. Lowering the room temperature and intermittent heating of a room are effective methods for reducing heating energy consumption. These techniques were proven in our previous studies by modelling simulations. To confirm the simulations schedule controllers, which automatically turned off the ondol heating in the living room and kitchen from 10 pm to 6 am, were installed at the hot water distributor in five households. The heating gas used in each of the housing units was measured over a period of 5 years, with and without the schedule controllers. We found that approximately 30% of gas consumption, mainly used for heating, can be saved compared to turning on the appliance during the night.

Introduction

Korea depends on overseas sources for 97% of its energy. The energy consumption for heating or hot water supplies in residential buildings accounts for a large proportion, approximately 13%, of the national energy requirement. In particular, the heating method and residential pattern in apartment buildings, which includes approximately 58% of all housing units as of the end of 2008, have been mostly standardised, which has greatly impacted energy savings. On the other hand, through precedent research, room temperature, ventilation, extended balcony and window space, and intermittent heating of apartment buildings were proved to have a great influence on heating energy consumption [1–3].

Despite the fact that approximately 8% of heating energy is saved by lowering room temperature by one degree, many residents fail to do so voluntarily. For instance, although a room temperature of 20°C is recommended, Korean houses are usually set to about 24°C due to ondol radiant heating and the influence of Korean living habits over the years [4].

In Korea, since the middle of 2000, each room of most new apartment buildings has its own zone temperature

Los Angeles, London, New Delhi and Singapore
DOI: 10.1177/1420326X09358033
Accessible online at http://ibe.sagepub.com
Figures 1–3 appear in colour online

H. Hong,
Department of Mechanical Engineering, Kyung Hee University,
Yongin 446-701, Korea. Tel. +82-31-201-2925, Fax +82-31-202-2625,
E-Mail hhong@khu.ac.kr

controller, thereby saving energy throughout the system; however, apartment buildings built prior to that period do not have this feature. One other effective method for saving energy in existing apartment buildings is to replace the windows by those with better insulation. However, high installation costs have been an obstacle for a widespread change-over. In an earlier study, a simulation analysis was done to investigate the energy saving effect of intermittent heating [5]. Shutting off the heat in an unused space is a very efficient and economic way to save energy. Although most people actually turn off the heat when all family members leave the house, they are unaware of the energy saving effect of turning off the heat overnight in their living rooms and kitchens. It is difficult to find cases of zone temperature controller utilization even in new apartment buildings despite their capability for lowering the temperature in unused spaces at a preset time.

As a consequence, the present study was conducted to provide more realistic energy saving measures with the Heating Schedule Control technology of Korean apartment housing units. To do so, we conducted experiments on residential apartment buildings to determine how much heating energy and carbon dioxide emission can be reduced by shutting off ondol hot water supply in unused rooms, including the living room and kitchen, overnight.

Methodology

Ondol and Heating Controller

Ondol is a unique Korean heating method, a kind of radiant heating that heats the floor to a relatively low temperature. The comfort, energy savings, and environmental benefits of Korea's ondol system are becoming more well known, and Japan has already begun using floor heating (Yukadambo). Moreover, approximately 50% of new apartment buildings in Western Europe have an ondol feature, and the ondol market in the United States has been growing over 20% per year, showing the growing interest worldwide.

The modern ondol system is built by installing hot water coils under the floor, through which 60–70°C hot water is circulated thereby heating the floor to around 30°C. The general structure of a hot water ondol system is shown in Figure 1, in which the heat flows indoors through an upper layer of hot water coils, and polystyrene and polyurethane insulation are installed under the pipes to prevent an outflow of heat [6].

The hot water coils are typically 16 mm diameter plastic tubing, and the length of a section was once limited to less than 50 m. However, currently there is no length limit as the regulation was removed in 1999. Figure 2 shows an example of an installation.

In order to supply the proper amount of hot water to each section with different lengths of hot water coils, a hot water distributor is installed, and a rough plan is shown in Figure 2. Hot water heated in a boiler or heat exchanger gets distributed to each section through the supply header of the hot water distributor. Manual and electronic fine-flow valves are installed to shut off the hot water and to fine tune the flow. Through the boiler's capacity control, manual valve, exact flow control, and proportional control of the heating controller, the room temperature in each section may be adjusted.

Prior to the middle of 2000, most housing units had temperature sensors in the living room or bed room, and the room temperature was generally controlled by on–off control of the boiler. The manual valve was closed slightly to lower the temperature in a certain room and could be completely shut off for long periods of inactivity.

The hot water distributor is normally installed in a cramped space, such as the bottom of a kitchen sink.

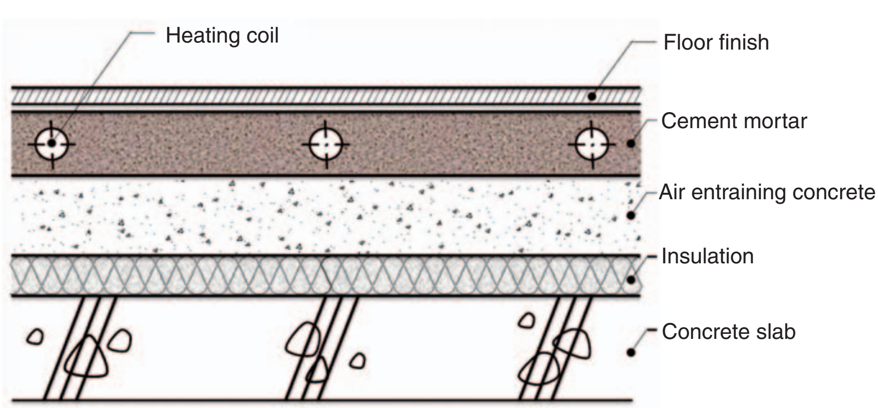

Fig. 1. Section of ondol heating.

Because of this, the repeated operation of opening and closing the valve for the heating system is very cumbersome. Therefore, energy saving by shutting off the heating for a room has been limited to closing the valve in an unused room or suspending boiler operation when all family members leave the house.

Most apartment buildings built after the middle of 2000 have a zone temperature controller. This allows different temperatures to be set for each room and at specific times, which helps save energy. With the difficulty and lack of awareness about operating zone temperature controllers, not many households practice saving energy through the schedule controller by regulating the heating of certain rooms at specific times.

Experimental Study

This study involved the installation of hot water distributors in existing apartment buildings with no prior heating controller, adding automatic valves and valve actuators, as shown in Figure 3, and then measuring the consumed heating energy before and after installation.

The heating of hot water was categorised into unit heating, central heating, or district heating, depending on its manufacturing method. Although district heating has been introduced in large-scale complexes of new cities, unit heating by gas boilers is still mainly used in private houses and in most apartment buildings. Therefore, the houses in this study were evaluated as unit heating houses, and the effect in reducing heating energy was measured via gas consumption. An automatic valve was installed only for hot water coils in the living room and kitchen. The size of the living room and kitchen usually takes up over 50% of most apartment buildings, so it was judged that leaving these rooms unheated overnight would have a significant effect in reduction of the overall heating energy.

Table 1 is a summary of the evaluated apartment buildings. All targeted apartment buildings were located in a metropolitan area, including Seoul and Suwon. The time period in which the ondol heating was turned off by the schedule controller varied slightly by household living pattern. The installation at each housing unit was done in the second half of 2006, and the actual experiment was conducted from November. The factor that had the most influence in determining the heating load was outdoor temperature, and the monthly average outdoor temperatures in Seoul since November 2004 are shown in Table 2.

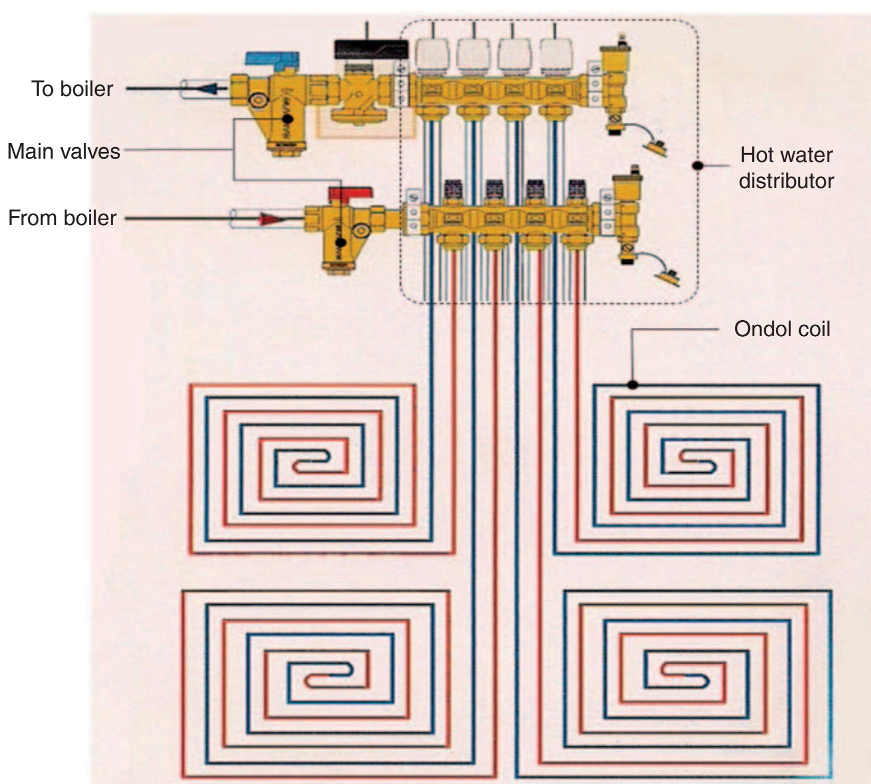

Fig. 2. Ondol coil with hot water distributor.

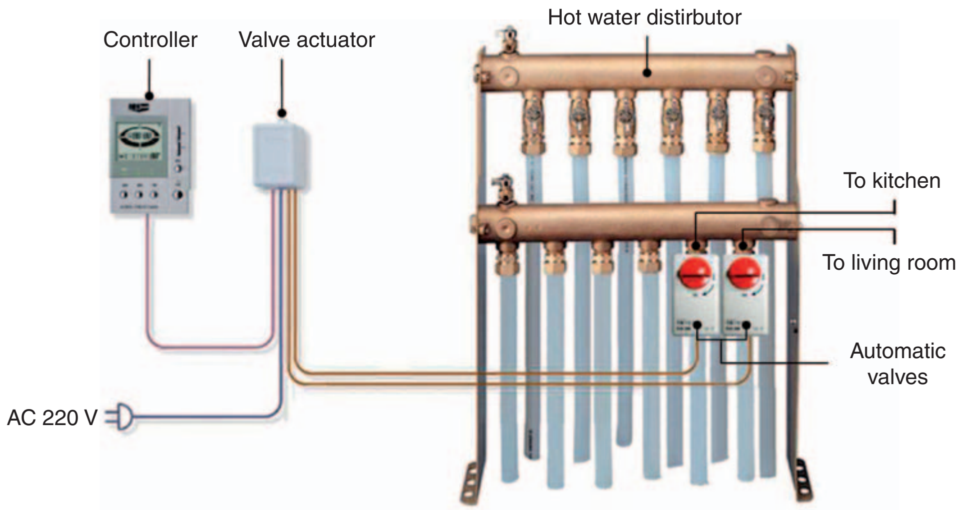

Fig. 3. A hot water distributor with a controller and automatic valve.

Table 1. Conditions of apartments

Apartment	Area (m^2)	Location	Time shutting off hot water
A	112	Seoul	22:00–07:00
B	179	Suwon	20:00–06:00
C, D	99	Gimpo	22:00–06:00
E	139	Siheung	22:00–06:00

Table 2. Monthly average atmospheric temperatures in Seoul

Year	Nov.	Dec.	Jan.	Feb.	Mar.	Average
2004–2005	9.1	1.9	−2.5	−1.9	4.1	2.14
2005–2006	8.6	−3.9	−0.2	0.1	5.2	1.96
2006–2007	8.4	1.4	0.4	4.0	6.1	4.06
2007–2008	6.7	1.8	−1.7	−1.2	7.3	2.58
2008–2009	7.6	1.1	−2.0	2.9	6.0	3.12

Results

Table 3 shows monthly gas consumption for 2 years prior to controller installation and for 2–3 years after controller installment. For apartment buildings C and D, the schedule controllers were removed as the residents had changed, preventing the collection of further data. Even though the size and time period of heating shut off were slightly different, the controller reduced gas consumption by 25–30%, on average. However, the reason why the average savings rate of the B apartment building is notable is because heating was shut down for 2 h longer than in the other apartment buildings, as shown in Table 1. The corresponding carbon dioxide reductions are presented in Table 3.

Besides heating, the amount of city gas consumed includes usage for hot water supply and cooking. Unless separate measurments are performed, it is impossible to obtain accurate values for the amount of energy consumed just for heating [7]. The city gas supplied for district heating is used for cooking, and the annual average usage of gas for cooking was easily calculated via survey; the average annual useage was shown to be ~7.5 m^3/month. Calculating the amount of energy consumed for hot water supply was more complicated, since the actual temperature changes depend on outside air temperature and the season. According to survey data, annual gas consumption for heating water is about 11.5 GJ, and the monthly average value increases 1.5 times during the winter [8]. If the efficiency of a residential gas boiler is set at 80% with a lower calorific value of 44.2 MJ/m^3, the gas consumption for hot water during the winter can be estimated to be 40.3 m^3/month. The estimate of the heating energy reduction is shown in Table 1 after deducting 50 m^3/month from the monthly gas usage. The heating energy was presumed to have saved as much as 30–35% from this.

As shown in Table 3, the reduction in city gas usage and carbon dioxide production varies considerably depending on building size. In Korea, apartment buildings of ~100 m^2 account for 1/4 of entire apartment buildings. The A, C, and D apartment buildings in this study were examples of such apartments, for which annual average city gas consumption can be reduced by 280 m^3 (equivalent to 0.3 toe of petroleum), while that of carbon dioxide can be reduced by 625 kg.

Table 3. Data and results

Apartment	Year	Gas amount (m^3)							Reduction ratio (amount)			Heating reduction ratio	
		Nov.	Dec.	Jan.	Feb.	Mar.	Sum	Average					
A	2004–2005	38	236	276	272	199	1021	1013	25.3%	257 m^3 [a]	573 kg [b]	33.7%	(19.1%)
	2005–2006	133	255	246	203	168	1005						
	2006–2007	103	143	192	134	162	734	756					
	2007–2008	151	185	196	202	140	874						
	2008–2009	90	154	167	135	115	661						
B	2004–2005	266	343	528	551	456	2144	2121	38.8%	822 m^3 [a]	1834 kg [b]	43.9%	(38.3%)
	2005–2006	353	515	483	362	385	2098						
	2006–2007	138	278	377	114	392	1299	1299					
	2007–2008	133	244	606	343	92	1418						
	2008–2009	171	202	271	267	269	1180						
C	2004–2005	130	210	300	240	190	1070	1141	29.2%	334 m^3 [a]	744 kg [b]	37.5%	(39.1%)
	2005–2006	130	340	200	291	250	1211						
	2006–2007	105	189	194	192	185	865	807					
	2007–2008	121	180	149	175	124	749						
D	2004–2005	94	188	228	194	217	921	1001	24.9%	249 m^3 [a]	555 kg [b]	33.2%	(34.7%)
	2005–2006	131	170	289	116	375	1081						
	2006–2007	156	180	163	147	170	816	752					
	2007–2008	93	140	152	150	153	688						
E	2004–2005	94	201	200	746	307	1548	1642	26.0%	427 m^3	953 kg [b]	30.70%	(24.6%)
	2005–2006	154	622	384	299	276	1735						
	2006–2007	290	248	203	191	243	1175	1214					
	2007–2008	169	364	286	237	173	1229						
	2008–2009	240	293	267	230	209	1239						

[a]Saved gas amount; [b]Reduced CO_2.

Discussion

Before the experiment, the possibility of reducing heating energy by (50%)(8/24) = 17% was expected if the heating of the living room and kitchen, which represent over 50% of apartment building area, were shut off for 8 h. The fact that energy consumption was reduced much more than this, was because the heating load also decreased, while it usually increases overnight when the outside air temperature is lower than the day time. Also, cases of 24 h heating is actually rare, and, considering the fact that people generally turn off the boiler when all family members leave the house, the reduction was even greater than expected. On the other hand, there is a need to determine the influence of outside air temperature before and after shutting off the heating. For instance, if the average outside air temperature was exceptionally low prior to installation, increased energy consumption would result. As shown in Table 2, the outside air temperature in December 2005 before controller installation was significantly lower than average, about two degrees lower than the same time period in 2006 and 2007, after installation.

Therefore, it is important to compare the outside air temperatures of 2004 and 2005 with those of 2007 and 2008, which is shown in the parenthesis of the right most column of Table 3 as the reference reduced rate. Except for the A apartment buildings, the others were quite similar when their average reduced rates were compared, showing at least a 20% heating energy savings.

The energy saving effect achieved by shutting off the heating was considered to have a close relation to the ondol heating method. The most significant features of ondol heating are its storage effect and its ability to heat with a relatively low temperature of below 70°C, which, however, slows the system response when heating is controlled. The reason for relying on the on–off control rather than ratio control for setting room temperature is because of this slow response [9,10]. The periodic on–off control is generally set for a few hours.

The convector heating method has a good loading response and has excellent control in maintaining a certain temperature. In fact, the savings in heating energy by shutting off the heating of a given room was not that significant in a Transient Systems Simulation Program (TRNSYS) simulation, based on convection heating. The causes for this were simply analysed. When shutting off the heating in the living room and kitchen overnight, there is a greater load placed on the other rooms.

Also, when the heating is resumed in the living room and kitchen in the morning, the temperature of the nearby rooms decreases 2–4°C more than usual. However, with its excellent control, convection heating raises the indoor and drywall temperatures by maximising the load on the heater, and the heating energy consumed during this period offsets a significant portion of the overnight reduced energy. More detailed calculation and analysis are needed to draw a conclusion on this fact. Since this phenomenon cannot occur in ondol heating with its inferior following load, this system leads to heating energy savings.

Therefore, after heating was resumed at dawn, the morning temperature in the living room was somewhat low, but residents did not complain about this temperature difference. In fact, residents were unaware of the existence of the installed automatic schedule controller.

In such experiments, it is difficult to conduct strict comparisons because each household has different environments. In subsequent research, the adequacy of heating energy savings by shutting off the heating to specific rooms is expected to be verified through simulations with precise ondol modeling.

Conclusion

The reduction of heating energy use and carbon dioxide production has been confirmed through experiments which turned off heating in the living room and kitchen overnight. The examined households were not aware that the experiments were being conducted, and the residents did not have problems with the 2–4°C lower morning temperature in their living room.

The actual test results show the possibility of reducing heating energy use and carbon dioxide production by 30–35% via the shut off of ondol heating for about 8 h overnight. It had the effect of reducing 0.3 toe of fuel useage and 625 kg of carbon dioxide annually for a 100 m^2 sized apartment building.

Such a reduction in heating energy and carbon dioxide can be made for housing units with zone temperature controllers by utilizing the schedule controller feature, and existing apartment buildings without this feature can easily install a schedule controller in the living room and kitchen.

There is a need for government agencies to recognise the effect of shutting off heating as a measure to reduce fossil fuel consumption and carbon dioxide production in the short term. Also, as a realistic energy-saving measure in residential buildings, there should be a promotion to lower indoor temperatures by 2–3°C, and energy saving by shutting off the heating in the living room and kitchen overnight should be actively encouraged.

Acknowledgment

This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science and Technology (No. 2009-0063383).

References

1 Yoo H, Hyun SK, Hong H: Effects of various factors on the energy consumption of Korean-style apartment houses: Korean J Air Con Refrig Engineer 2005;14(11):972–980.

2 Kwon YI, Han HT: A study on the evaluation of air change efficiency of multi-air-conditioner coupled with ventilation system: Int J Air Con Refrig 2007;15(7):101–107.

3 Yang JH, Seok HT, Lee SJ: A study on the application of a ceiling plenum ventilation system in an apartment house: Indoor Built Environ 2009;18(3):234–244.

4 Song DS, Kang KN, Park DR: A prediction of the indoor air movement and contaminant concentration in a multi-room condition: Int J Air Con Refrig 2007;15(3):135–146.

5 Park YW, Yoo H, Hong H: Analysis of heating energy in a Korean-style apartment building 3: the effect of room condition settings: Korean J Air Con Refrig Engineer 2005;17(8):722–728.

6 Samyang Valve: Design for ondol hot water heating and header, 2003.

7 Lee BJ, Chung DY, Lee S, Hong H: Analysis of heating energy in a Korean-style apartment building 2: the difference according to heating type: Korean J Air Con Refrig Engineer 2004; 16(5):459–466.

8 Choi BS, Kim JH, Kang YT, Hong H: Verification experiment and analysis for 6 kW solar water heating system (Part 2: modelling and simulation): Korean J Air Con Refrig Engineer 2004;16(6):556–565.

9 Seok HT: A study on the control methods of hydronic radiant floor heating system: J Korean Soc Living Environ Sys 1999;6(2):30–35.

10 Steskens PWMH, Janssen H, Rode C: Influence of the convective surface transfer coefficients on HAM building performance: Indoor Built Environ 2009; 18(3):245–256.