Analysis of heating behaviour based on occupancy patterns in residential building with radiant floor heating system

Jisoo Shim[1], *Doo-sam* Song[2*]

[1]Department of Civil and Environmental System Engineering, Graduate school of Sungkyunkwan University, 2066 Seobu-ro, Jangan-gu, Suwon 16419, Republic of Korea
[2]School of Civil, Architectural Eng., and Landscape Architecture, Sunkyunkwn University, 2066 Seobu-ro, Jangan-gu, Suwon 16419, Republic of Korea

Abstract. To achieve a carbon-neutrality, a reduction of heating energy consumption in residential building should be achieved. Although, lots of building energy policies were implemented to reduce heating energy consumption, it still accounts the largest share of global building energy consumption. Large number of researches pointed out the poor heating energy management by occupant makes inefficient heating energy consumption. In this research, the occupancy patterns and heating behaviour in Korean residential building are analysed. The occupancy patterns are identified with electricity consumption collected from 229 households. By comparing the heating energy consumption and occupancy patterns, the heating behaviour in residential building is analysed. The results show that about 81.2% of the analysed households applied continuous heating strategy whether occupants stay in the building or not. About 39.5% of the total heating energy consumption in 229 households, is consumed during unoccupied hours. The result of this research shows that the heating control strategy considering occupancy patterns can be greatly reduce the heating energy consumption in residential building.

1 Introduction

Heating energy consumption in residential building accounts over half of the global building energy consumption[1]. As an importance of carbon-neutrality is increasing, it is considered that reducing heating energy consumption in residential building is unavoidable. Therefore, Lots of countries have actively implemented building energy policies to reduce heating energy consumption in residential building[2]. E.g. improving building thermal performance, applying high efficiency heating system etc. Despite of these efforts, the heating energy consumption in residential building still increasing. And the effect of building energy policies seems unclear.

IEA[3] explained the main reason for this situation comes from the occupant's poor heating energy management. Theoretically, the heating energy only be consumed for satisfying the occupant's thermal comfort. When occupants doesn't stay in building(unoccupied), the heating energy no need to be consumed. Lots of precedent researches reported that HVAC systems continuously operated even though occupants leave the building. Maximum 56 % of the building energy is excessively consumed by occupant's poor energy management[4]. Therefore, it is assumed that the heating control strategy considering occupant can effectively reduce the heating energy consumption in residential building[3].

For reducing heating energy consumption in residential building by applying proper heating control strategy, occupancy patterns in residential building should be redefined. Occupancy pattern is an important parameter not only analysing the heating behaviour by occupant also assessing the effect of heating control strategy in residential building.

It shows an information about occupancy ratio(occupied or unoccupied) during a day. The general occupancy pattern in residential building[5] define that occupants stay for 24 hours in the building. Although, the occupancy patterns in residential are diversely changed as changing the life style, it still be accepted as the general pattern[6]. With existed occupancy pattern, the heating control strategy for residential building cannot be proposed properly. Also, it cannot be used for reducing the heating energy consumption in residential building. The goal of this research is analysing the possible heating energy reduction in application of heating control strategy considering occupancy patterns in residential building. This paper consisted with three research processes. First, occupancy patterns in residential building will be redefined using electricity consumption data collected from 229 households. Second, the heating behaviours in residential building are analysed by comparing the heating energy consumption based on the occupancy patterns. Finally, the excessive heating energy consumption in residential building is analysed and suggests the necessity of heating control strategy considering occupancy patterns.

* Corresponding author: dssong@skku.edu

2 Methods

2.1 Analysis building

In this research, multi-residential building is chosen as an analysis building (Fig. 1 and Table 1). Multi-residential building is a representative type of residential building in Korea. It occupies 78.3% of the residential building in Korea[7]. The analysis building was built in 2019, and is a high energy performance building following Korean building energy regulation.
There are 135 multi-residential buildings in Korea, which were built around the same period as the analysis building. The analysis building shows medium value of annual heating energy consumption(from 2019 to 2020) among 135 multi-residential buildings[8]. Therefore, it can be considered that the analysis building shows a general heating behaviour in Korean residential building. There are 229 households in the analysis building. Every households equipped the radiant floor heating system. The hourly building energy consumption data(heating, DHW, electricity, gas for cooking) were collected from the whole households. These data are measured from August 2019 to July 2020.

Fig. 1. Picture of analysis building.

Table 1. Information of analysis building.

	Elements
Location	Seoul, Korea
Type of building	Multi-residential building
Year of completion	2019.10
Unit area	36, 44 ㎡
Number of households	229
Heating system	Radiant floor heating
Heat source	District heating

2.2 Occupancy detection in residential building

2.2.1 Zero-training algorithm for occupancy detection

The occupancy pattern is consisted with occupancy detection dataset for a day. Lots of methods to detect the occupancy are suggested. However, existed methods cannot be applied especially in residential building. Because of privacy problemns, problems for installing the detecting instruments etc., the detecting real-time occupancy in residential building is very limited.
Becker et al[9]., suggested occupancy detection method using only the electricity consumption data. It assumes that the electricity consumption is dramatically changed depending on the occupancy. Based on this idea, Becker et al., suggested zero-training algorithm for occupancy detection. The algorithm is as follow below,

$$y(t)=\lambda \cdot x(t)+(1-\lambda)\cdot y(t-1) \quad (1)$$

$$If\ x(t) \geq y(t),\ occupied,\ 1. \quad (2)$$

$$If\ x(t) < y(t),\ unoccupied,\ 0. \quad (3)$$

t is the time steps, x(t) is the electricity consumption at time t. y(t) is the averaged electricity consumption until t. λ determines the importance of recent values over older values. In precedent research, λ is suggested as 0.05.
This method can overcome the existed methods. Because it only requires electricity consumption data from residentail building. If the electricity consumption data are gathered from various households, the general occupancy patterns in residential buildings can be identified.

2.2.2 Validation of the occupancy detection method

The zero-training algorithm for occupancy detection is validated before applying to the analysis building. The household, showing same condition with the analysis building, is analyzed for the validation. Real-time occupancy data and hourly electricity consumption data are collected simultaneously during one month(January 2022).
The occupancy detection method is appplied using electricity consumption data. And the accuracy to predict the occuapncy detection is assessed with real-time occupancy data. Fig. 2 shows the accuracy of the occupancy detection method. The method can predict occupancy detection with the 94.6 % accuracy. The validation result shows that the occupancy detection method using electricity consumption data can be applied to redefine the occupancy patterns in residential building.

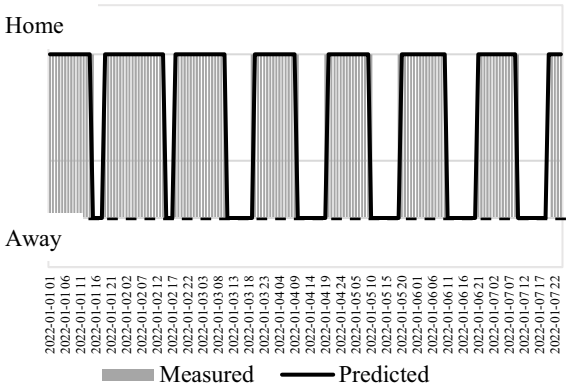

Fig. 2. Validation results of occupancy detection method using real-time measured occupancy data

In application of the occupancy detection method for analysis households(229 households), 83,585 occupancy patterns are drawn(229 households ·365 days). By applying K-means clustering method, occupancy patterns are grouped which shows similar characteristics.

3 Results

3.1 Occupancy patterns in residential building

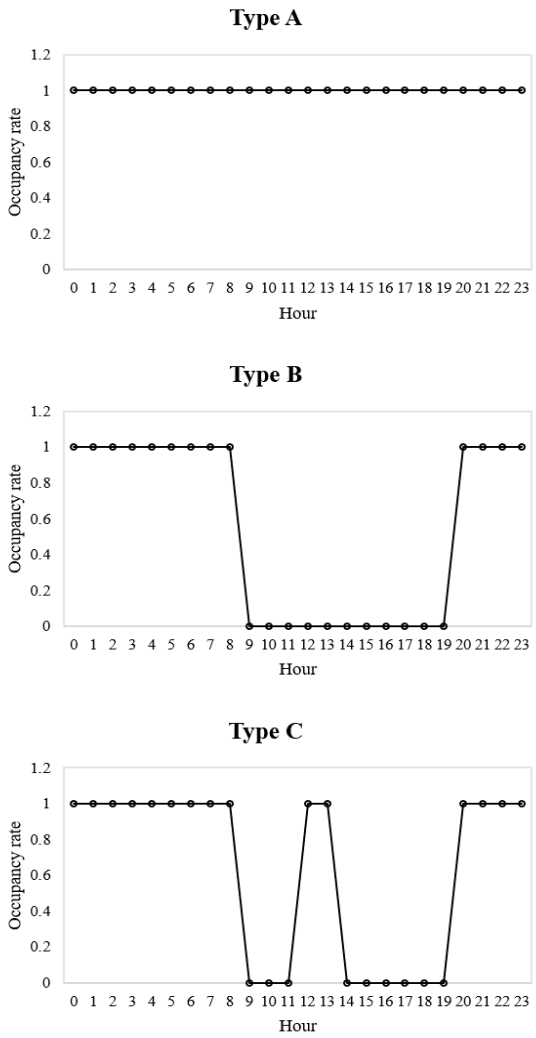

Fig. 3. Occupancy patterns in residential building.

3 different occupancy patterns are identified from the analysis(Fig. 3).
The households where the occupants stay for 24 hours during a day, shows the occupancy pattern as Type A. Only 7.7% of the analysed households shows this pattern. Type A is same with the general occupancy pattern in residential building.
Most of the households show the occupant pattern as Type B. It is appeared in the households where the occupants leave during the daytime. Except the daytime, occupants stay in the household. The occupants are presumed that go to work or school. It accounts 64.4% of the analysis households.

Type C is appeared in the households where the occupants leave during the daytime. The difference with the Type B is occupants return to the residential building for a short period of time during the day. 27.87% of the analysis households show the Type C.
The result shows that the occupancy patterns in residential building are greatly different from the general pattern. Also, it is appeared that the occupancy patterns are diversified depending on the households.

3.2 Analysis of heating behaviour in residential building

The heating behaviour in residential building is analysed by comparing the hourly heating energy consumption with the occupancy pattern(occupied and unoccupied).
For the households where occupants stay for 24 hours in the residential building (Type A), it is reasonable to consider heating system also is operated constantly. Therefore, the heating behaviour is analysed for the households showing Type B and C.

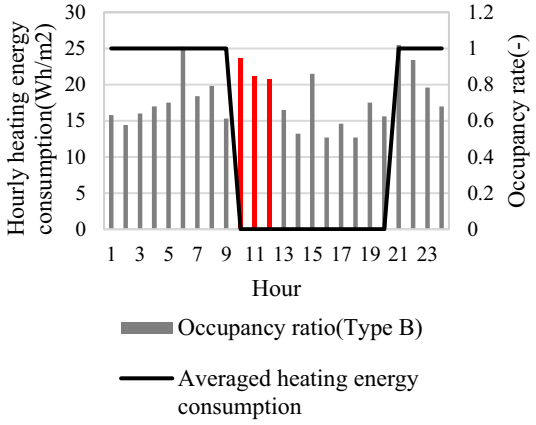

Fig. 4. Hourly heating energy consumption in Type B

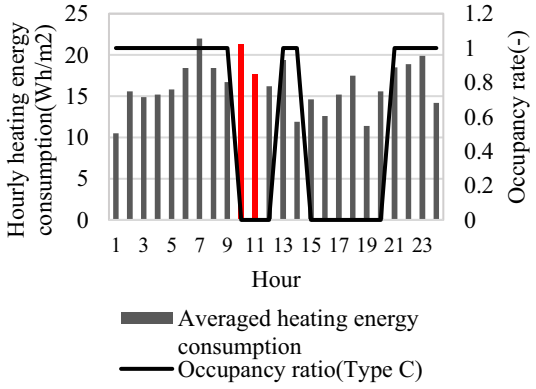

Fig. 5. Hourly heating energy consumption in Type C

Among the households showing Type B and C, 81.2% of these households operates the heating system even occupants leave the building. Shortly, they apply continuous heating strategy. It means most of occupants

in residential building manage the heating energy improperly. Fig. 4 and 5 are the hourly heating energy consumption in the households showing Type B and C respectively.

The amount of heating energy consumption is different depending on the type of occupancy patterns. But large portion of heating energy is consumed during unoccupied hours. Especially, the right after the time when occupants leave the residential building, the heating energy consumption increases dramatically. There is no need to be consumed the heating energy consumption during unoccupied hours. However, large number of heating energy is inefficiently consumed by the poor heating energy management

3.3 Reducible heating energy in residential building with heating control strategy

Fig. 6 shows the total heating energy consumption of 229 households from August 2019 to July 2020. The total heating energy consumption is distiguished depending on the occupancy patterns.

The heating energy consumption in the analysis building(229 households) was 1079.4 kwh/㎡·yr. Among 39.5%(426.9 kwh/㎡·yr) of the total heating energy is consumed during the unoccupied hours. It is because occupants apply the continuous heating control strategy regardless of there occupancy patterns. The result shows that the necessity of heating control strategy considering occupancy patterns. When proper heating control strategy is applied in residential building, the same amount of wasted heating energy during the unoccupied hours can be reduced.

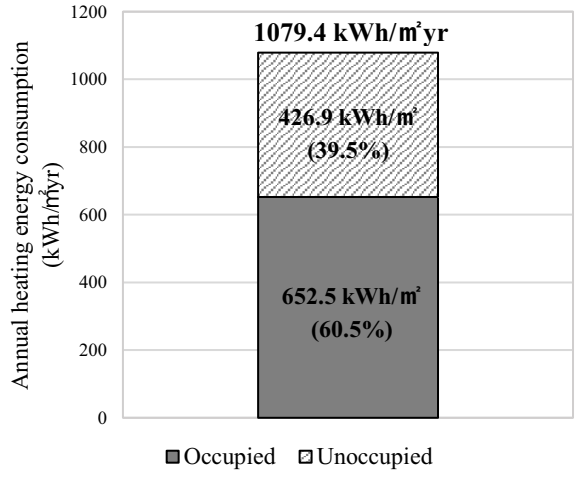

Fig. 6. Heating energy consumption by occupancy patterns

4 Conclusions

To reduce the heating energy consumption in residential building, the building energy policies focus on improving the energy performance of the building. However, the effect of reducing heating energy consumption was insignificant. The poor heating energy management by occupant is considered the main reason of increasing the heating energy consumption.

For reducing heating energy consumption in residential building applying heating control strategy, the occupancy patterns in residential building should be identified.

In this research, the occupancy patterns and heating behaviour in Korean residential building are identified. The heating and electricity consumption data from 229 households are gathered. Using electricity consumption data, the occupancy patterns are analysed. Contrary to the general occupancy pattern in residential building, 3 types of occupancy patterns are identified. It means the occupancy patterns are diversified and changed as changing the life style. Most of occupants in residential buildings are shows the occupancy pattern which coexist the occupied and unoccupied activities. 81.3% of these households applied continuous heating whether occupants stay or not in the building. And the heating energy consumed during the unoccupied hours accounts for 39.5% of 229 households. The result of this paper proved the amount of wasted heating energy consumption by the occupants. Also, the result supported the necessity of heating control strategy considering occupancy pattern. It is considered that the heating control strategy considering occupancy pattern can be reduced same amount of heating energy as wasted during the unoccupied hours. Additionally, the occupancy patterns identified in this research, can be used for proposing the heating control strategy in residential building.

References

[1] Agency IE. Buildings 2021.
[2] Hamilton I, Rapf O, Kockat DJ, Zuhaib DS, Abergel T, Oppermann M, et al. 2020 global status report for buildings and construction. United Nations Environmental Programme. 2020.
[3] Agency IE. Heating. 2022.
[4] Masoso OT, Grobler LJ. The dark side of occupants' behaviour on building energy use. Energy and buildings. 2010;42(2):173-7.
[5] ASHRAE A. Standard 90.1-1989. Energy Efficient Design of New Buildings except Low-Rise Residential Buildings. 1989.
[6] Santin OG. Behavioural patterns and user profiles related to energy consumption for heating. Energy and Buildings. 2011;43(10):2662-72.
[7] Korea S. Population and housing census in 2021. 2022.
[8] board Kre. K-apt. 2022.
[9] Becker V, Kleiminger W. Exploring zero-training algorithms for occupancy detection based on smart meter measurements. Computer Science-Research and Development. 2018;33(1):25-36.

Acknowledgement

This work was supported in part by the Public Building Green Remodeling Support Program through the Ministry of Land, Infrastructure, and Transport(Korea Authority of Land and Infrastructure Safety) of Korean Government under B0060210000039.