A study on passive and active behaviors of the occupants for thermal adjustment in a HEMS condominium

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The energy use in residential sector is increasing than other sectors in Japan. One of its reasons is the increasing use of mechanical air conditioning. Therefore, there is much interest in designing low energy buildings. How the occupants behave for the thermal adjustment is one of the determining factors for energy use but much has not yet been clarified yet. An understanding of behavioral patterns of the occupants residing in any types of houses and should be useful for designing comfortable homes with less energy use. HEMS (Home Energy Management System) visualizes the energy use so that it might be useful to understand how the occupants use energy for heating and cooling. The use of HEMS is increasing in different countries including Japan. Some studies doubt the effectiveness of the HEMS and suggest redesigning it considering the occupants behaviors in HEMS use. The study on passive and active behaviors in the studied HEMS managed house showed that the occupants equally adapted passive way along with the use of air conditioning for thermal adjustment. The window opening behaviors of the occupants showed that the proportion of window opening was high in FR mode. The occupants mostly used heating as the outdoor air temperature reached below 15°C and cooling when the temperature raised above 25°C.

1. Introduction
Local and global climates change, economic growth and the increasing use of electrical appliances have resulted in a significant increase of energy use for heating and cooling in residential sectors. In 2010, the global cooling of the residential sectors was almost 4.4% of the total heating and cooling needs of the buildings. It is expected to increase up to 35% in 2050 and 61% in 2100 [1]. The penetration of air conditioning is very high in USA and Japan, approaching almost the highest possible saturation level [2]. So, it is important to design and construct residential buildings which require low energy use for heating and cooling which are effective for improving thermal comfort. Buildings with less thermal loss more likely to provide better thermal comfort. Along with good building envelop design, efficient energy management system also plays an important role for low energy usage while maintaining indoor thermal comfort.

Occupants residing in any types of buildings adapt passive and active methods to indoor thermal environment given by and maintain their thermal comfort inside the buildings. Commonly, passive methods are window opening and clothing and active methods are mechanical heating and cooling. One of the primary means to improve energy use in buildings is to incorporate the best energy-saving system into new buildings [3]. Since, Home Energy Management System (HEMS) visualizes the rate and total of energy use; it might be useful for common people to understand how they use energy. The use of HEMS is increasing in different countries including Japan. Some studies showed that the HEMS could not become popular among common people [4, 5]. And some researchers suggested that the occupants’ behaviors should be focused and redesigned for its effective use [5, 6]. There are some studies related to how different algorithm and automatic systems help to control heating and cooling with HEMS use [7, 8] but there is no study to understand how the occupants behave to use passive and active methods with HEMS use.

The objective of this study is to understand how the occupants behave in terms of passive and active methods for thermal adjustment.

2. Methodology
2.1 Study area
A HEMS managed residential building as shown in the Figure 1, located at Katsushima Shinagawa was selected. This study was conducted with the information given by the occupants of Katsushima building. In this building 356 families live.

Figure 1 Residential Building (Katsushima)
2.2 Thermal measurement
The device as shown in Figure 2 was installed with HEMS in the building to record indoor air temperature, relative humidity and illuminance. The measure values were recorded at the interval of either 2 or more up to 10 minutes. The outdoor temperature was from the nearest meteorological station.

2.3 Online survey
Questionnaire survey was conducted for the purpose of knowing occupants’ behaviors by the occupants for thermal adjustment. Altogether 17026 votes from 33 males and 37 females from 47 families were received during the one-year survey period from November 2015 to October 2016. The received votes were divided into the groups of free running (FR), cooling (CL) and heating (HT) modes. FR is the mode of not using any types of heating and cooling devices, CL is the mode of using air-conditioning unit cooling devices and HT is the mode of using heating devices. Heating can be made air conditioning unit, floor heating system, and gas-fired heater and so on but here, heating represents only air conditioned heating.

3. Results and discussions
3.1 Monthly indoor and outdoor air temperature
First, the monthly indoor and outdoor air temperatures were compared to observe how the indoor air temperature relates to outdoor air temperature variation. Figure 3 shows the variation of monthly mean indoor air temperature together with outdoor air temperature in FR mode. The mean indoor air temperature is always higher than outdoor air temperature because of various heat gains but the rise and fall of indoor air temperature look influenced by outdoor air temperature. In January, February and March, the mean indoor temperature stays constant at around 21°C, though the outdoor air temperature was changing below 10°C. Since Figure 3 is for FR mode, the heating devices such as air conditioning unit and others were not operated; therefore the fact that the average indoor air temperature stayed rather constant during winter season for December to March suggests that it is the combined effect of heat capacity of all flats surveyed. The indoor temperature increased from the beginning of April and reached almost 29°C in August which is observed as the highest mean indoor temperature of the studied building in FR mode. The outdoor air temperature is also the highest in August but it is 2°C lower than indoor air temperature.

![Figure 3 Indoor and outdoor air temperature with 95% confidence interval (Mean ±2 S.E.)](image)

3.2 Clothing adjustment
Clothing influences heat exchange between human body and the thermal environment, contributing to thermoregulation by creating a moderate micro-climate within the fabric layer [9]. Previous studies [10, 11] have proved that clothing is equally adjusted to maintain thermal comfort in different research area. The monthly mean clothing insulation analysis in the studied area as shown in Figure 4 has the similar trend of clothing compare to the study made by Watanabe et al. conducted in Gifu area of Japan [12]. The mean clothing insulation is 0.71 clo. The mean clo is 0.65 (n=11176), 0.40 (n=965) and 0.94 (n=4839) in FR, CL and HT mode respectively.

![Figure 4 Monthly mean clothing insulation with 95% confidence interval (Mean ±2 S.E.)](image)

3.3 Window opening
The proper opening and closing of windows can help to regulate the thermal environment so that it is important as one of the adaptive behaviors [13]. Thermal discomfort is caused by the indoor globe temperature and opening a window produces a mixing of indoor and outdoor air (when outdoor air temperature is low) and help to drop the indoor air temperature [14].

The condition of window opening was observed to analyze how the occupants were adjusting thermal comfort in terms of natural way of thermal adjustment. Figure 5 showed that the
occupants were equally using window open in different months but the proportion is high in May, June and July. The proportion of window opening decreased in November and December. The reason must be the occupants started using heating.

We further analyzed by dividing the total data according to voting time temperature into 10 (deciles) groups of around 1000 number of data in each group and the mean temperature of that particular group was taken. The mean outdoor air above 20°C in increasing order was taken to observe window opening behaviors of the occupants for thermal adjustment. As can be seen in Figure 6, the proportion of the window opening increased as the outdoor air temperature increased. When the mean outdoor air temperature is between 26.1-30.4°C almost 30 to 60% kept the window open.

As shown in Figure 3, the indoor air temperature is higher than 28°C in July and August which is regarded to be the upper limit of the recommended set-point temperature in Japan. We tried to analyze how the occupants have adapted to the thermal environment represented by higher indoor temperature. A large proportion of the occupants were using fan when the indoor air temperature is above 28°C (Figure 7). As the indoor air temperature increased the proportion of the occupants using fan also increased. Possibly, this behavior of the occupants must have helped them to adjust thermal comfort even for the condition of high indoor air temperature.

As shown in Figure 9, the proportion of AC unit use increased as the mean outdoor deciles air temperature increased. When the mean outdoor air temperatures are 25.7 and 31.3°C, the proportion of AC users are 15% and 42% respectively.

3.4 Fan use

3.5 The use of air-conditioning units for cooling

Although, the passive cooling is significant however; the overall performance of the passive cooling is heavily climatic dependent and may not be enough to satisfy the proper indoor comfort requirements under all climatic conditions [2]. Under such circumstances the use of mechanical cooling is necessary to adjust indoor temperature for thermal comfort. The use of air-conditioning cooling was observed in this building to know how the occupants have adjusted the thermal comfort in summer. Figure 8 showed that the percentage of AC unit use increased as the temperature increased in July and August. In August, about 46% of votes were under the condition of mechanical cooling.
3.6 The use of air-conditioning unit for heating
The occupants want to be comfortable in the variety of conditions using heating. In very cold time, it may be too hard or inefficiently to maintain the comfort of a consistent air temperature. Heat is required for thermal adjustment. Figure 10 showed that the use of heating is increased as the mean deciles outdoor air temperature decreased. Under the condition of the outdoor air temperature is below 10°C, around 25 to 30% proportion of the occupants using heating.

![Figure 10 Heating use and outdoor air temperature](image)

4. Conclusions
From the passive and active methods analyze on the studied building, we obtained the following result.
1. The clothing insulation highly influenced by outdoor temperature. The clothing trend is similar to other studies.
2. The window opening behaviors of the occupants is high in June and July if compare to August. A high proportion of the occupants adjusted thermal comfort in passive mode.
3. The use of fans is equally used for thermal adjustment.
4. The cooling is used when the outdoor air temperature is above 20°C. The large proportion used cooling when the outdoor air temperature is 31.7°C.
5. The heating was used when the outdoor air temperature is below 20°C. When outdoor air temperature is below 10°C, the large proportion of heating is observed.

Acknowledgments
We would like to thank to all the dwellers of the investigated HEMS managed building of Katsushima participating on online survey.

References