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A Study on Seasonal Thermal Environment and Active Behaviours of the Occupants Living in a Condominium under the Use of Home Energy Management System (HEMS)

Rajan K C, Hom Bahadur Rijal

[1]Department of University Counseling, Nepal Education Center, Tokyo, Japan
[2]Department of Restoration Ecology & Built Environment, Tokyo City University, Tokyo, Japan
Email: rkcrajandang@gmail.com

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Abstract

The use of Home Energy Management System (HEMS) is increasing worldwide for the effective use of energy inside the building. The Japanese government aims to set up HEMS for all of the new dwellings by 2030. Thermal comfort is associated with the trend of energy use in a building. In order to find out the seasonal thermal environment and thermal behaviors of the occupants for thermal comfort adjustment living in smart houses, we conducted a questionnaire and measurement survey in a condominium with 18 floors and 356 families equipped with HEMS. Indoor air temperature and relative humidity were measured for one year and the data was analyzed. The questionnaire survey was conducted online to understand the thermal behaviors of the occupants. The result showed a large variation in indoor air temperature during different seasons. The occupants behaved differently according to the seasons. The indoor air temperature of some of the flats in summer was observed even higher than as recommended temperature setting in Japan. They maintained thermal comfort by adopting active behaviors like changing clothing insulation, and using fan and window opening. Due to high insulating materials used in the building, the indoor air temperature was not that much lower even in winter without the use of any electric heating devices. The result indicates that the occupants behaved differently to adjust the indoor thermal environment even during the use of smart HEMS.

Subject Areas

Adaptive Thermal Environment

Keywords

HEMS, Indoor Environment, Air Temperature, Relative Humidity, Thermal Behaviors

1. Introduction

Household energy use has been increasing due to increasing use of modern appliances like air conditioning units, computers, electric vehicles, DVDS etc. which are basically used to make the lifestyle easier and more comfortable. For sustainable energy use, it is important to manage energy use effectively. Energy management in an effective way is more important in building sectors, especially in residential buildings because the huge amount of energy is used in residential buildings and residential energy use is increasing day by day worldwide. Effective energy management system are the major concerns of buyers in housing corporate sectors worldwide including Japan [1]. HEMS are linked from the visualization of electricity used to create a smart home to power control of home appliances. The number of electric appliances used at home determines the electricity use and influences indoor thermal environment in domestic buildings [2]. So, the use of HEMS might be useful for visualizing energy used by different electrical appliances and controlling the waste of energy.

Thermal comfort is defined as "that condition of mind which expresses satisfaction with the thermal environment" [3]. Indoor thermal comfort is associated with the trend of energy used for heating and cooling appliances in a building. The use of mechanical heating or cooling is the main passive thermal behaviors of the occupants for indoor thermal comfort adjustments during summer and winter. The use of heating appliances can change the thermal environment of any building in any region [4]. Those living in the coldest region may enjoy a sufficiently warm built environment, while on the other hand, those in temperate regions may not perceive warmth enough due to a lack of proper heating systems [5]. But, over heating or cooling may result in excessive energy use and energy waste. There are different guidelines for indoor heating and cooling use but those existing guidelines are inappropriate and need to be made more flexible [4]. Thermal comfort in both residential and office buildings relates to the outdoor thermal condition. It is believed that with mechanical heating and cooling have a narrower air temperature range than without it. But, even in mechanical heating and cooling use there might be wide range of indoor air temperatures based on active behaviors of the occupants.

In order to know the indoor thermal environment and air temperature range equipped with HEMS, we conducted a long-term measurement and questionnaire survey and its data was analyzed.

The results will be useful to understand actual thermal environment and the variation of air temperature based on outdoor air temperature in smart living.

The result might be useful for effective use of HEMS as well.

2. Methods

A HEMS managed residential building in the Shinagawa ward of Tokyo Japan had been selected for this study. The study site is in south-west of Tokyo metropolitan area. The general climatic profile is warm and temperate. Annual precipitation is 1469 mm. The hottest month is August with an average maximum temperature of 31.6˚C and the coldest is January with an average minimum temperature of 1.8˚C. The monthly average relative humidity is highest in September and it is 86%. The lowest is in January and it is 54.7%. Annual outdoor air temperature and indoor air temperature is described in Section 3.1.

An eighteen-storied condominium with 356 families shown in Figure 1(a) was selected for this study. Most of the studied flats in the condominium are 3 LDK (3 bedrooms, one living room including dining and one kitchen) and a few are 4 LDK (4 bedrooms, one living room including dining and one kitchen). The area of the flats varies from 71 to 90 m^2.

We kept measurement device as shown in Figure 1(b) in 356 flats of the studied condominium. Measurement was carried out at an interval of 2 - 10 minutes to understand the indoor air temperature, relative humidity and lighting. The outdoor air temperature was taken from the Tokyo Meteorological Station, which is just 13 km away from the study area. The measured data has been averaged to a 10-minute interval to match the 10-minute interval of outdoor air temperature. The questionnaire survey is conducted online.

(a) (b)

Figure 1. The studied building and the device used for measurement.

3. Results

3.1. Monthly Indoor and Outdoor Air Temperature

The relationship between monthly mean indoor and mean outdoor air temperatures was investigated to understand how the indoor air temperature fluctuated corresponding to outdoor air temperature. As shown in Figure 2, the fluctuation

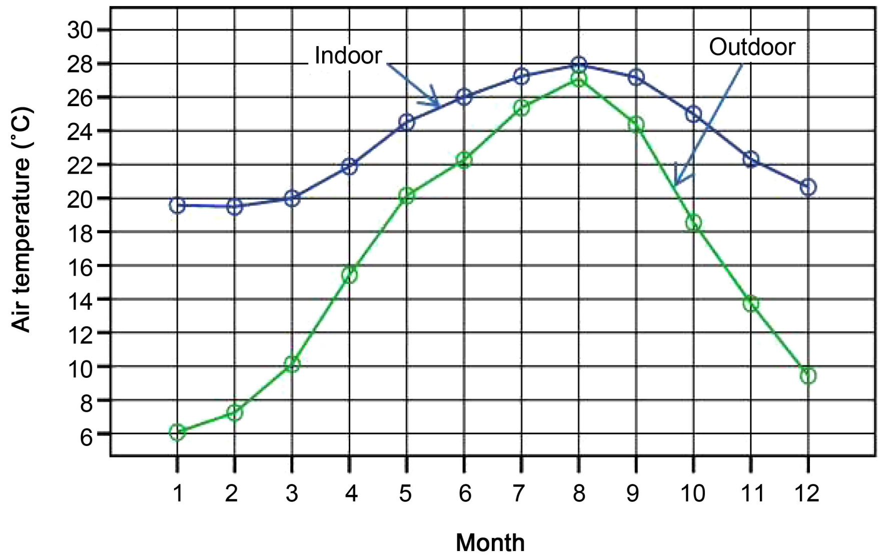

Figure 2. Monthly indoor and outdoor air temperatures.

of indoor air temperature is quite similar to that of outdoor air temperature but the amplitude is smaller. Realized indoor air temperature is different from one month to another. The difference between indoor and outdoor air temperature is large in January and small in August. The indoor air temperature is almost 20˚C for the months with monthly outdoor air temperature below 10˚C; that is, in January, February and March. The highly insulating materials used in the building is one of the causes of this temperature difference besides heating use, because similar trend is observed even with those flats of less use of heating devices, which was estimated from the indoor air temperature variation trend. Similar results have been obtained from the study done in residential buildings in China and England [6] [7].

3.2. Seasonal Indoor and Outdoor Air Temperature of the Studied Flats in Different Seasons

The seasonal variation of the indoor air temperature along with outdoor air temperature is observed to understand the influence of seasonal change. **Figure 3** shows the relationship between indoor and outdoor air temperatures in respective four different seasons for the whole year. We found the seasonal variation of indoor air temperature in the studied building. The mean air temperature is 27.1˚C in summer and 20˚C in winter. The indoor air temperature in spring and autumn seasons tend to be highly correlated to the outdoor air temperature The autumn mean air temperature is 2.1˚C lower than summer and 3˚C higher than spring seasons. In winter season, the indoor and outdoor air temperature difference is quite large; the indoor air temperature is much higher than outdoor air temperature. It is due to the highly insulating materials used in the building along with the use of heating. In summer, the difference between indoor and outdoor air temperature is quite small.

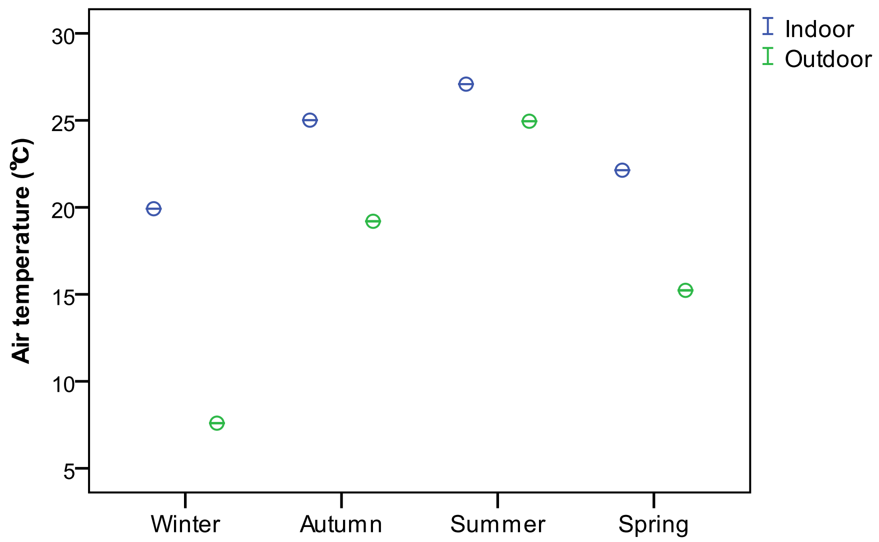

Figure 3. Seasonal differences in indoor air temperature.

3.3. Seasonal Differences in Indoor Air Temperature by Months in Different Floors

We observed the mean indoor air temperature of four months representing to all seasons according to the floors. As shown in Figure 4, the result showed that the mean indoor air temperature ranged from 19˚C to 31.5˚C in different seasons in different floors. The seasonal changes of indoor air temperature does not necessarily look consistence with each other. For example, the indoor air temperature of floor 15 has the highest temperature among all the floors in January, but floor 9 has the highest temperature among all the floors in August. The difference between indoor and outdoor air temperature is high in January and low in August. This suggests that the indoor environment has been influenced by the occupants' behaviors rather than floor level in the studied condominium.

3.4. Seasonal Differences by Location

The mean indoor air temperatures with 95% confidence interval (Mean ± 2 S.E.) in two different positions (center and corner) were analyzed from the measured data according to seasons. Figure 5 shows that the location of the flat in the building has influenced the indoor air temperature in different seasons. Flats at the center have slightly lower higher temperature than the flats at the corner. The studied condominium has the south main orientation so the flats in the center lose heat from north and south sides only, but the flats located at the corner lose heat from three sides including east side for east corner flats and west side for west corner flats.

3.5. Indoor and Outdoor Relative Humidity

Relative humidity depends on temperature. It requires less water vapour for high relative humidity at low temperatures and more water vapour for high relative humidity in high temperature. Figure 6 shows that the indoor relative humidity

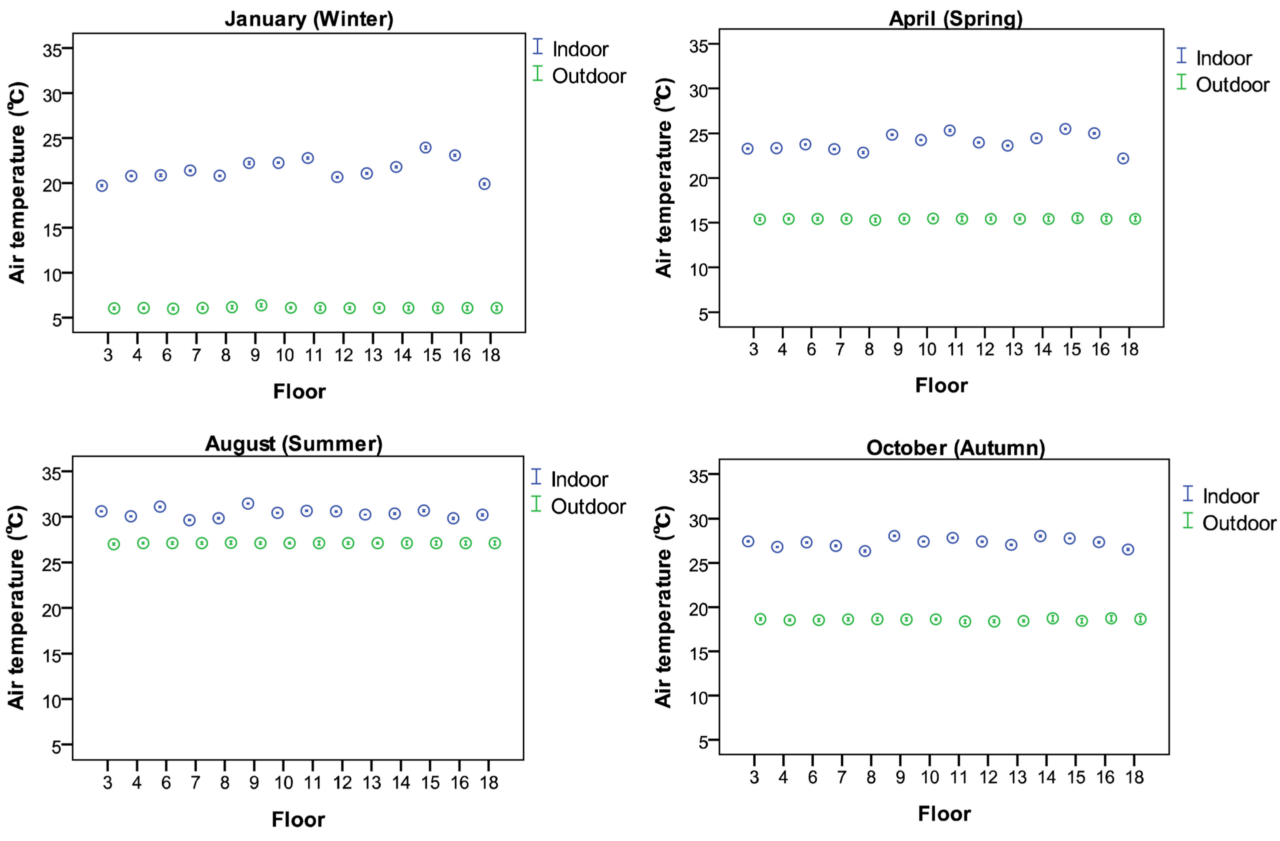

Figure 4. Floorwise indoor air temperature of representing months of all seasons.

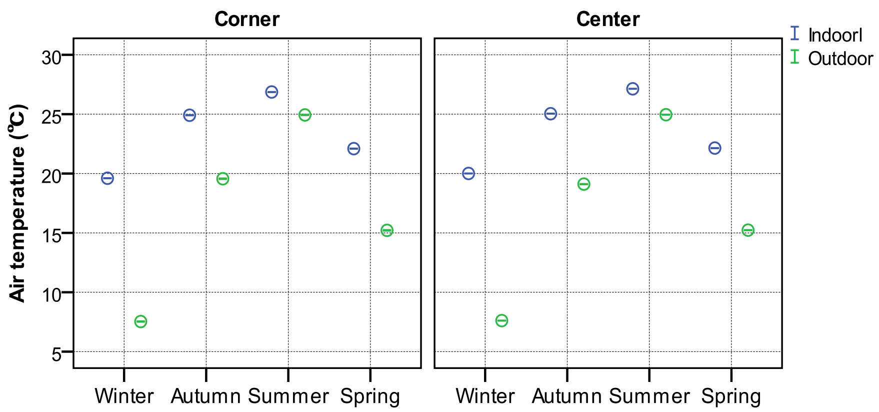

Figure 5. Indoor air temperature according to the location.

is consistent with outdoor relative humidity in different seasons though the indoor relative humidity is lower than the outdoor. Possibly, the use of humidifiers and dehumidifiers is not so high.

3.6. Clothing Behaviours

Clothing influences heat exchange between the human body and the thermal environment, contributing to thermoregulation by creating a moderate micro-climate within the fabric layer [8]. Previous studies [9] [10] have proved that

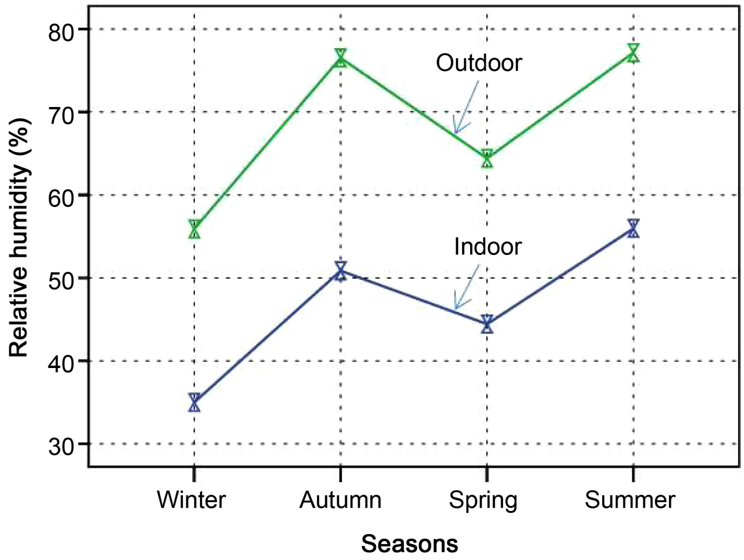

Figure 6. Seasonal indoor and outdoor relative humidity.

clothing is equally adjusted to maintain thermal comfort in different areas.

The monthly mean clothing insulation analysis in the studied area as shown in Figure 7 has the similar trend of clothing compared to the study made by Watanabe *et al*. conducted in Gifu area of Japan [11]. The mean clothing insulation is 0.71 clo.

3.7. Window Opening

The proper opening and closing of windows can help to regulate the indoor thermal environment so that it is one of the important adaptive behaviours [12]. 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. The condition of window opening was observed to analyse how the occupants were adjusting thermal comfort in terms of natural way of thermal adjustment. Figure 8 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 mechanical heating.

3.8. Fan Use

As shown in Figure 2 the indoor air temperature is higher than 27˚C in July, August and September which is regarded to be the upper limit of the recommended temperature set-point in Japan. We tried to analyse how the occupants have adapted to the thermal environment represented by higher indoor temperatures. A large proportion of the occupants were using fan when the indoor air temperature was above 27˚C (Figure 9). FR is the condition when the mechanical cooling has not been used and CL is the condition when the mechanical cooling is used. As the indoor air temperature increased, the proportion of the occupants

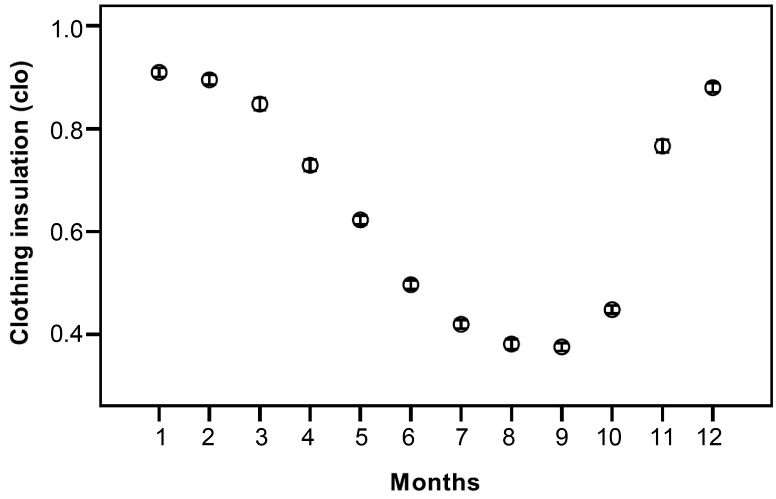

Figure 7. Monthly mean clothing insulation with 95% confidence interval (Mean ± 2 S.E.).

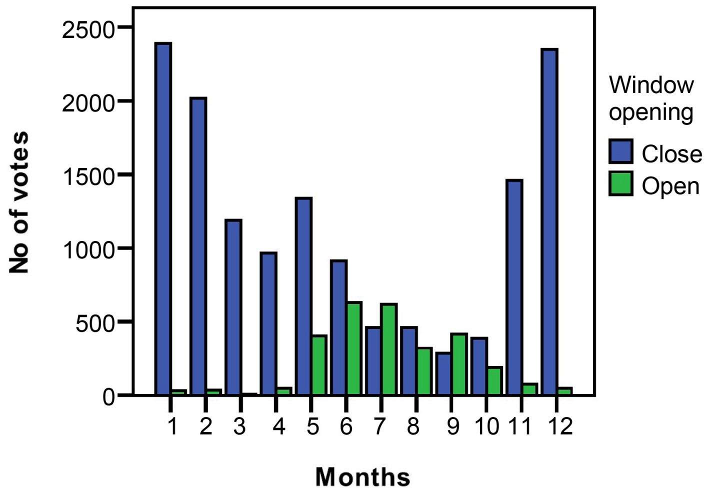

Figure 8. Window opening behaviours.

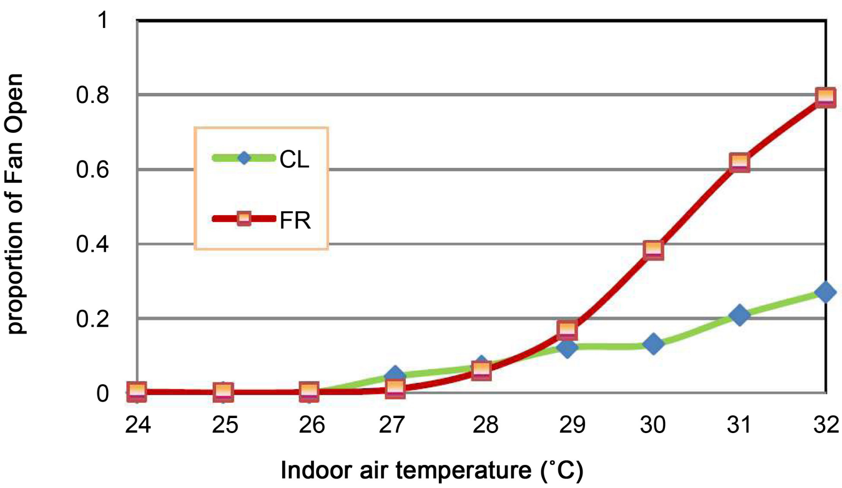

Figure 9. Fan use and indoor air temperature.

using fan also increased. Possibly, this behaviour of the occupants must have helped them to adjust thermal comfort even for the high indoor air temperature [13].

4. Discussion

Generally, it may be considered that the occupants become fully dependent on the use of mechanical system for thermal environment if they live in smart houses because the energy use can be self-controlled or by automatic systems. The studied condominium is equipped with HEMS, which provides the occupants with the information about indoor and outdoor temperature condition, weather information or the amount of energy used for a particular device used indoors. So, the occupants living with such system can adjust the indoor thermal environment favorable to them with the use of mechanical heating and cooling.

But the results obtained here in this study showed that the occupants were not fully dependent on the mechanical system only because the temperature variation in not uniform. The behaviors of the families differed from one to another. The occupants living in this condominium are adapting various other activities like changing clothing insulation, using fan and window openings besides the use of mechanical system. During summer, the indoor air temperature of some of the flats was higher than the recommended temperature for cooling that is 28˚C in Japan. The analysis so far proves that the adaptive behaviors have influenced the indoor thermal environment rather than the fully use of mechanical energy management system. Fanger's PMV and PPD models exclude the occupants' adaptive behaviors [14]. However our results emphasize considering the adaptive behaviors of the occupants as well as predicting the actual thermal environment of the occupants.

If this knowledge is considered during the development and installation of any smart energy management system, it may be more applicable and long lasting.

5. Conclusions

From a series of analyses on the data collected by thermal measurement survey conducted in a HEMS condominium in Shinagawa, Tokyo metropolitan area in Japan, we have found the following results.

1) The indoor air temperature in the studied condominium was not similar according to flats or floors.

2) The location of the flats at the center or corner has influenced the indoor thermal environment.

3) Daily, monthly and seasonal differences were observed in indoor air temperatures and relative humidity.

4) The clothing insulation was highly influenced by outdoor temperature.

5) The window opening behaviors of the occupants are high.

6) In June, July is compared to August. A high proportion of the occupants

were adopting active behaviors even with the use of HEMS.

7) The fans are equally used.

Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] Transparency Market Research's New Market Research Report 2015. Home Energy Management Systems Market—Global Industry Analysis, Size, Share, Growth, Trends and Forecast 2013-2019.

[2] Firth, C., Lomas, S., Wright, K. and Wall, A.R. (2016) Identifying Trends in the Use of Domestic Appliances from Household Electricity Consumption Measurements. *Energy and Buildings*, **40**, 926-936. https://doi.org/10.1016/j.enbuild.2007.07.005

[3] ASHRAE Standard 55 (2004) Thermal Environment Conditions for Human Occupancy, Atlanta.

[4] Nicol, F. (2017) Temperature and Adaptive Comfort in Heated, Cooled and Free-Running Dwellings, *Building Research & Information*, **45**, 730-744. https://doi.org/10.1080/09613218.2017.1283922

[5] Cao, B., Luo, M., Li, M. and Zhu, Y. (2016) Too Cold or too Warm? A Winter Thermal Comfort Study in Different Climate Zones in China. *Energy and Buildings*, **133**, 469-477. https://doi.org/10.1016/j.enbuild.2016.09.050

[6] Jo Luo, Q., Yang, L., Liu, N.X. and Xia, J. (2015) Comparative Study on Thermal Environment and Energy Consumption of Urban Residential Houses in Beijing. *Procedia Engineering*, **121**, 2141-2148. https://doi.org/10.1016/j.proeng.2015.09.085

[7] Huebner, G.M., McMichael, M., Shipworth, D., Shipworth, M., Durand-Daubin, M. and Summerfield, A. (2013) The Reality of English Living Rooms—A Comparison of Internal Temperatures against Common Model Assumptions, *Energy and Building*, **66**, 688-696. https://doi.org/10.1016/j.enbuild.2013.07.025

[8] Shimazaki, Y., Goto, S., Yoshida A. and Yamamoto, T. (2017) The Effect of Solar Radiation on Temperature Distribution in Outdoor Human-Clothing-Environment System. *Heat and Mass Transfer*, **104**, 1-6. https://doi.org/10.1016/j.ijheatmasstransfer.2016.08.022

[9] Rijal, H.B, Yoshida, H. and Umemiya N. (2010) Seasonal and Regional Differences in Neutral Temperature in Nepalese Traditional Vernacular Houses. *Building and Environment*, **45**, 2743-2753. https://doi.org/10.1016/j.buildenv.2010.06.002

[10] Indraghanti, M. (2010) Using the Adaptive Model of Thermal Comfort for Obtaining Indoor Neutral Temperature: Findings from a Field Study in Hyderabad, India. *Building and Environment,* **45**, 519-536.

[11] Watanabe, K. and Rijal, H.B., (2013) Investigation of Clothing Insulation and Thermal Comfort in Japanese Houses. *PLEA Conference*, Munich, 10-12 September 2013.

[12] KC, R., Rijal, H.B., Shukuya, M. and Yoshida, K., (2018) An *in-Situ* Study on Occupants' Behaviours for Adaptive Thermal Comfort in a Japanese HEMS Condominium. *Journal of Building Engineering*, **19**, 402-411. https://doi.org/10.1016/j.jobe.2018.05.013

[13] KC, R., Rijal, H.B., Shukuya, M. and Yoshida, K., (2018) An Investigation of the Behavioural Characteristics of Higher-and Lower-Temperature Group Families in a

Condominium Equipped with a HEMS System, *Buildings*, **9**, Article 4. https://doi.org/10.3390/buildings9010004

[14] Fanger, P.O. (1972) Thermal Comfort, Analysis and Application in Environmental Engineering. McGraw-Hill, New York.