Effects of humidity on the relation between temperature and thermal control use during summer–autumn

Noriko Umemiya*, Koichi Taniguchi, Xiaoyong Lin and Ryoji Okura

Osaka City University

*Corresponding email: umemiya@arch.eng.osaka-cu.ac.jp

SUMMARY
Indoor and outdoor temperature and humidity, air conditioner use, status of window opening, and occupation were measured for 10 concrete apartments constructed according to the same simple plan in Osaka during summer–autumn. Only one air conditioner was installed for 1–2 occupants for each apartment. Temperatures were classified by 1–2°C; relative humidity was classified by 5–10% and the humidity ratio by 1–2 g in each bin of temperature. The mean ratio of control use was calculated for each bin of humidity only when the apartment was occupied. The relations were analyzed for three seasons divided according to the daily mean ratio of air-conditioner use. Results show that humidity is sometimes dominant in the choice of thermal control use. Sometimes, both temperature and humidity are unrelated to the choice. For the same temperature, the ratio of air-conditioner use is high and the ratio of opening is low when humidity is high.

KEYWORDS:
Air-conditioner use, Window opening, Humidity

INTRODUCTION
If occupants seek to lower the room temperature during a warm season, then two ways can be chosen: using the air conditioner or opening windows. Air-conditioner use has prevailed in almost all households in Japan's Kansai area. People choose a method under various constraints. Sound, air pollution, external appearance, money, and health might affect the choice. This study investigates effects of outdoor temperatures and humidity on the choice.

Earlier studies investigated relations between thermal control use and air temperature. Nicol et al. (2004) used a logit model to predict the opening ratio. Tanimoto et al. (2005) used a state transition probability function for air-conditioner use. Umemiya et al. (2006) modeled the ratio of air-conditioner use and window opening using linear regression. Humphreys et al. (2008) produced a behavior model of opening and closing windows. However, effects of humidity are not included in these models. Humidity also affects indoor thermal comfort, especially for hot and humid summers in Japan. Lower humidity mitigates thermal discomfort and might affect air-conditioner use and window opening.

METHODS
From a 10-story-high steel framed reinforced concrete apartment building with 222 rented apartments, 10 apartments were chosen. The simple plan of each unit––rectangular with one air-conditioner––was selected because of the simpler relation between the cooling method and indoor thermal conditions. Air temperature and humidity at 0.6 m from the floor were measured. The status of all openings was recorded by magnetic switches every 20 s. Air-conditioner use was judged from the air-conditioner temperature. Whether or not the

domiciles were occupied was inferred according to horizontal illuminance, the record of the opening of the front door, and an oral survey of residents.

The measured period was divided into a cooling season, a late cooling season, and a natural ventilation season based on the daily average ratio of air-conditioner use for the 10 apartments.

We define the house as 'open' if more than one window or door was opened. The ratio of the use of controls R for an apartment is defined as follows.

$$R = \frac{\sum_{t=1}^{T} \delta_t}{T} \qquad (t=1, 2, ..., T) \tag{1}$$

$$\delta_t = \begin{cases} 0 & : \text{'not used' at time } t \\ 1 & : \text{'used' at time } t \end{cases}$$

Therein, time t is defined only when the apartment is occupied.
The average ratio for n houses, R_{mean}, is defined as shown below.

$$R_{mean} = \frac{\sum_{i=1}^{n} \sum_{t=1}^{T_i} \delta_{t_i}}{\sum_{i=1}^{n} T_i} \qquad \begin{matrix} (ti=1, 2, ..., Ti) \\ (i=1, 2, ..., n) \end{matrix} \tag{2}$$

$$\delta_{ti} = \begin{cases} 0 & : \text{'not used' at time } t \text{ in house } i \\ 1 & : \text{'used' at time } t \text{ in house } i \end{cases}$$

In those equations, t_i and T_i represent t and T for apartment i.

RESULTS

Division of summer by daily ratio of air-conditioner use

Figure 1 shows the change of daily mean ratio of air-conditioner use and window opening, averaged for 10 apartments only when occupied. The ratio of air-conditioner use was less than 50% after 21 September and became almost zero after 14 October. The first apartment began to use heaters on 5 November. This study defines periods according to the use of air conditioners as follows: the cooling season lasts until 21 September; the late cooling season lasts until 13 October; and the natural ventilation season lasts until 4 November. The respective daily maximum and daily minimum outdoor temperatures for each season are 24.1 and 32.2°C, 18.6 and 26.5°C, and 13.3 and 21.2°C.

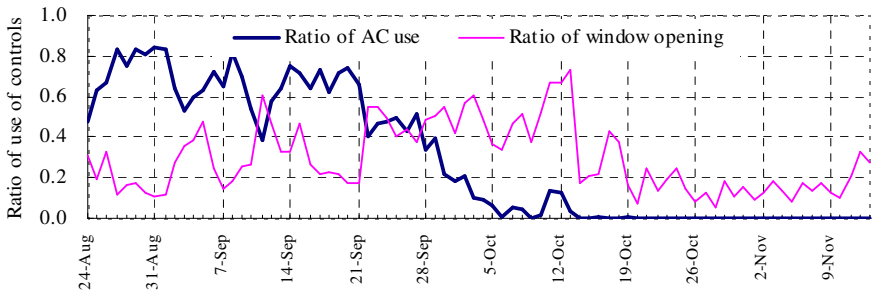

Figure 1. Change of daily mean ratios on AC use and opening

Effects of humidity on the ratio of control use

Figure 2 portrays relations between the outdoor temperature and ratio of air-conditioner use by outdoor humidity. Only values of humidity bins over a 5.0% distribution frequency are shown. During the cooling season, humidity has little effect on the relation. In the late cooling season, the ratio of air-conditioner use is less than 0.1; there is little difference in the ratio among different levels of humidity when the air temperature is 17–19°C. The ratio is higher for higher humidity for the same temperature when the air temperature is 21–27°C. Differences of the ratio among humidity levels are greater for higher temperatures. The relation is similar when the humidity ratio is applied.

Figure 3 shows relations between the outdoor temperature and the ratio of window opening by outdoor humidity. During the cooling season, the ratio is related neither to the temperature nor to humidity. In the late cooling season, the ratio of window opening does not change so much according to the outdoor temperature. It is lower for higher humidity except for 50% relative humidity at 23°C. The relation is similar, but the difference among humidity levels is not so clear when the humidity ratio is applied instead of relative humidity. During the natural ventilation season, the ratios are higher for lower humidity when temperatures are 15°C and 17°C. The relation between the ratio and humidity is not consistent when temperatures are 19°C and 21°C. It is as high as 0.8 for 50% when the temperature is 23°C. The tendency is similar when the humidity ratio is applied.

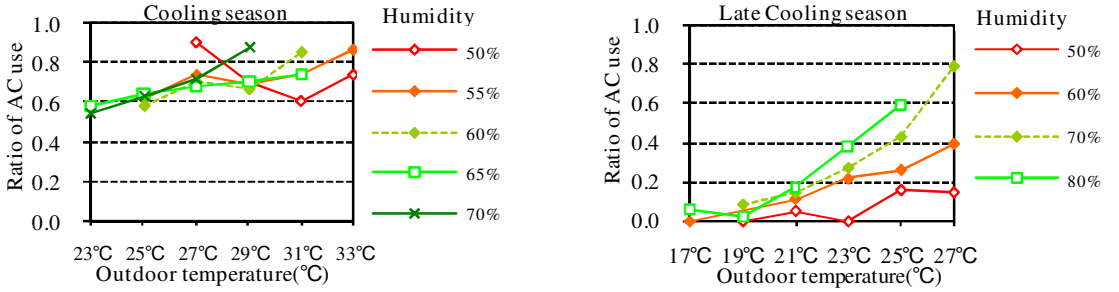

Figure 2. Relation between the temperature and ratio of air-conditioner use by humidity.

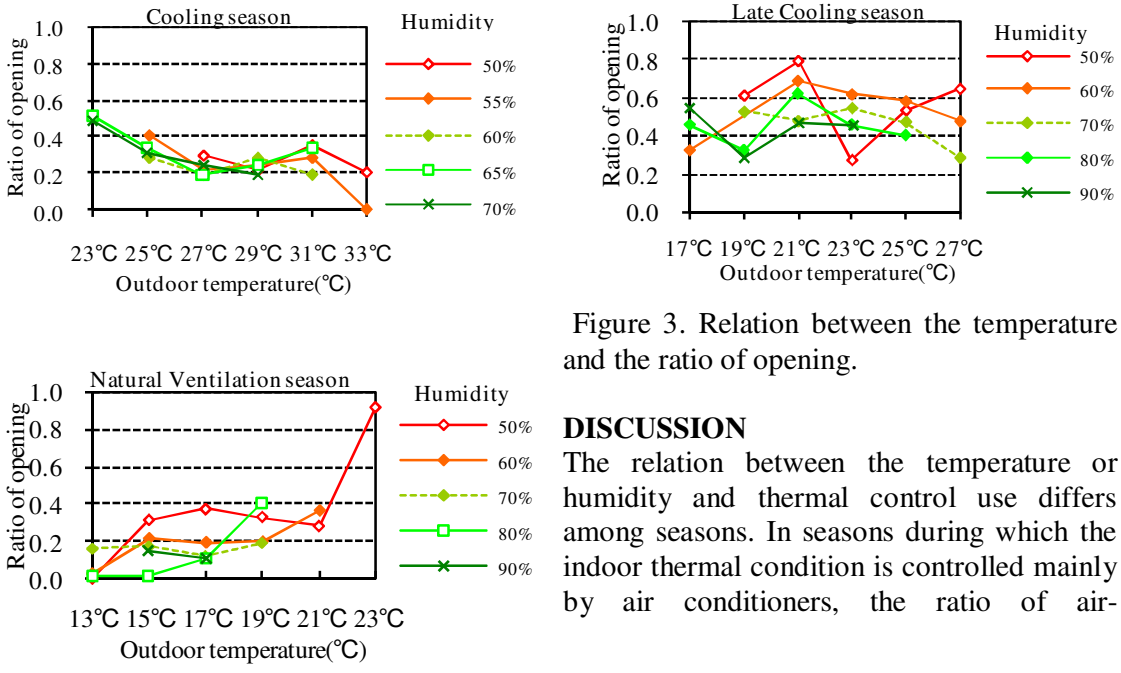

Figure 3. Relation between the temperature and the ratio of opening.

DISCUSSION

The relation between the temperature or humidity and thermal control use differs among seasons. In seasons during which the indoor thermal condition is controlled mainly by air conditioners, the ratio of air-

conditioner use is related to outdoor temperature, but not to humidity. The average daily mean temperature during the season was 32.2°C: reduction of indoor temperatures was the priority. The opening ratio is related neither to temperature nor to humidity. The temperature was too high to be controlled by window opening during the cooling season. The opening ratio was low, 0.2–0.3; windows were presumed to be opened for purposes other than thermal control.

During the late cooling season, when both mechanical and natural cooling are used, the ratio of air-conditioner use is higher for higher temperatures. It is higher for higher humidities for the same temperature. Averaged minimum and maximum daily temperatures were 18.6°C and 26.5°C, respectively, for the season. Occupants use air conditioners according to the temperature. Humidity is also considered. On the other hand, the opening ratio is almost constant for all ranges of temperatures. It is higher for lower humidity for the same temperatures. Window opening in this season depends more on humidity than on temperature.

During the natural ventilation season, when the indoor climate is controlled by window opening and closing, the opening ratio is higher for higher temperatures. Averaged daily minimum and maximum temperatures for the season were 13.3°C and 21.2°C. Windows were presumed to be shut for lower temperatures. When the temperatures were 15°C and 17°C, the opening ratio was higher for higher humidity. When the temperatures were 19°C and 21°C, no consistent relation was recognized between humidity and the opening ratio. Windows were presumed to be open irrespective of the humidity.

Effects of other climate conditions on the control behaviors were also investigated. Global temperatures indoors were measured at four apartments. Radiation was presumed to exert little effect because correlation coefficients were approximately 0.97 between air and global temperatures for each season. Further investigation is necessary because thermal inertia should be considered for comparing indoor and outdoor temperatures. This study clarified that thermal control use is related to temperatures in the range where thermal control functions effectively. For the range in which the control was not so effective, humidity relates to the control use. Effects of humidity are stronger than those of temperature in some cases.

CONCLUSIONS

Measurements clarified that humidity is related to thermal control use in the warm season. Given equal temperatures, the ratio of air-conditioner use is higher and the ratio of opening is lower for higher humidity. However, the ratio of air-conditioner use depends on the temperature and the ratio of opening depends neither on temperature nor humidity in seasons during which the indoor thermal environment is controlled mainly by air conditioners. The relations differ according to whether relative humidity or the humidity ratio is used.

REFERENCES

Humphreys M.A. et al. 2008. Modelling window-opening and the use of other building controls. In: *Proceedings of 29th AIVC Conference*, pp.91-97.

Nicol J.F. et al. 2004. A stochastic approach to thermal comfort - occupant behavior and energy use in buildings. *ASHRAE Transactions*, 110(2), pp.554-568.

Tanimoto J. et al. 2005. Cooling load simulation considering actual variation of inhabitants' behavior for accurate estimation of urban maximum energy requirement. In: *Proceedings of the 9th International IBPSA Conference*, pp.1205-1212.

Umemiya N. et al. 2006. Modeling the ratio of air conditioner use and window opening using indoor and outdoor temperatures during summer–autumn for apartment houses in Japan. In: *Proceedings of the 8th Healthy Buildings Conference*, pp.157-162.