Effects of Weather Conditions on Thermal Control use in Apartments during Summer–Autumn

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Abstract

Air conditioner use and window opening were recorded in Osaka during summer–autumn. The measured period was divided into four seasons according to the change of ratio of air conditioner use. In the former questionnaire survey of the reasons for opening and closing windows, 'fine weather' or 'rain' were ranked highly. This study investigated effects of weather conditions on the relation between temperature and humidity and thermal control use. Cloud cover was used as indices of weather conditions. Results showed that the ratio of opening was higher 1) for fine weather during the natural ventilation season for equivalent outdoor temperatures, 2) for cloudy weather in the late cooling season for equivalent indoor temperatures, 3) for cloudy weather in the late cooling season for equivalent outdoor humidity, and 4) for fine weather in the cooling season and for cloudy weather in the late cooling season for equivalent indoor humidity.

Keywords: Window opening, Air conditioner use, weather conditions

Introduction

Measurements of the relations between thermal control use and temperature and humidity during summer–autumn by Umemiya et al. (2009) show that 1) during the late cooling season, the ratio of air-conditioner use is higher for higher outdoor humidity for the same outdoor

temperature range. 2) During the cooling season, the ratio of air-conditioner use is higher for higher indoor humidity. 3) During the cooling season, the ratio of window-opening increases concomitantly with the indoor temperature for indoor RH of 50–60%. However, the ratio decreases as indoor temperature increases when the indoor RH is 65–75%. Nicol et al. (2004), Tanimoto et al. (2005), and Humphreys et al. (2008) investigated the relation between temperature and thermal control use. An earlier questionnaire survey by Lin et al. (2006) of the reasons for opening and closing windows during summer–autumn, however, revealed high rankings of responses indicating that windows were “opened because of fine weather” or “closed because of rain”, which suggest the effects of weather conditions on thermal control use. This study investigated effects of weather conditions on the relation between outdoor and indoor temperature and humidity and thermal control use during summer–autumn. Cloud cover measured at a meteorological observatory was used as an index of weather conditions.

Objectives

This study investigates whether the relation between thermal condition and thermal control use in apartments differs according to weather conditions or not. Results of a former questionnaire survey were checked. If those and current results differ, then to what degree does weather affect the results? Which is more affected by weather, air-conditioner use or

window-opening behaviors? Cloud cover is used as an index of weather conditions in this study. Weather is defined as “sunny” if the cloud cover is 0 and 1 and “cloudy” if the cloud cover is between 2 and 10.

Methods

Measured objectives were 10 small apartments having the same simple rectangular plan. Fig. 1 shows a plan of the apartment. The opening status of two windows, hinged doors to the veranda and the front door were recorded by magnetic switches every 20 s together with air temperatures at 0.6 m from the floor. The air-conditioner use was estimated using the inside air temperature of the air conditioners. Relative humidity at 0.6 m above the floor was recorded every 10 min. Temperature and humidity outdoors were measured at the rooftop of the building near the apartments. We define the apartment as ‘open’ when more than one window or door is open. The mean ratio of use of controls for apartments, $R_{COND,\,mean}$ is defined only for the time during which the residences are occupied, as

$$R_{COND,mean} = \frac{\sum_{i=1}^{n}\sum_{t=1}^{T} o_{t_i}\delta_{t_i}}{\sum_{i=1}^{n}\sum_{t=1}^{T} o_{t_i}} \quad , \qquad \text{(Eq. 1)}$$

where o_{ti} is o_t, the occupation at time t for apartment i. Here, o_t is 1 when occupied and 0 when not occupied. Also in that equation, δ_{ti} is δ_t, use of control for apartment i: δ_t is 1 when used and 0 when not used.

Fig. 2 portrays the change of the daily mean ratio of air-conditioner use and window opening, as averaged for 10 apartments when occupied. This study defines four periods, or seasons, according to the use of air conditioners as follows: the cooling season is 24 August – 21 September; the late cooling season is 22 September – 13 October; the natural ventilation season is 14 October – 3 November. This paper presents investigations of only the cooling season and late cooling season.

Results and Discussion

The relative frequencies of “sunny” weather when apartments were occupied during the cooling season, late cooling season, and natural ventilation season were 10.1%, 6.9%, and 36.3%, respectively, and 16.4% overall.

Fig. 3 shows the ratio of air-conditioner use for each bin of outdoor temperatures during the cooling season and late cooling season. These figures show that air-conditioner use is unaffected by weather conditions during the cooling season (Fig. 3-a).

During the late cooling season, the rate of air-conditioner use is higher for sunny weather than for cloudy weather when the outdoor temperature is 17–20°C. However, it is higher for cloudy weather when the outdoor temperature is higher than 22°C. It can be said that air conditioners tend to be used for cloudy weather with higher outdoor temperature and sunny weather with lower outdoor temperature during the late cooling season (Fig. 3-b).

Fig. 4 shows the ratio of air-conditioner use for each bin of the outdoor humidity ratio. Differences of the ratio by weather conditions are small for the same bins of outdoor humidity during the cooling season (Fig. 4-a).

During the late cooling season, the ratio of air-conditioner use is higher for sunny weather than for cloudy weather. The ratio is higher for higher outdoor humidity both for sunny and cloudy weather. Higher outdoor humidity lets the occupants use air conditioners (Fig. 4-b).

Fig. 5 shows the ratio of opening for each bin of outdoor temperature. During the cooling season, the opening ratio is higher for lower outdoor temperature bins when outdoor temperatures are lower than 27°C both for sunny and cloudy conditions. The opening ratio is higher for sunny than for cloudy when the outdoor temperature is lower than 27°C. The ratio is almost identical for the higher outdoor temperatures. When the outdoor temperature is lower, windows are opened for sunny weather, but they are closed for cloudy weather. However, windows are closed irrespective of the weather when the outdoor temperature is

higher. Apparently, 27°C is the extremal value of outdoor temperature for relation of thermal control use and weather during the cooling season (Fig. 5-a).

During the late cooling season, the ratio of opening is almost identical for sunny and cloudy conditions. The opening ratio has a peak when the outdoor temperature is lower than 24°C for sunny weather. However, the ratio is almost uniform for cloudy weather. Apparently, 24°C is the extremal value of outdoor temperatures for the relation of thermal control use and weather during the late cooling season (Fig. 5-b).

Fig. 6 shows the ratio of opening for each bin of outdoor humidity ratio. The opening ratio is higher for sunny conditions than for cloudy ones for humidity bins of 12 g/kg' to 14 g/kg' during the cooling season. It can be said that the windows are not always open when humidity is low. The opening depends on weather conditions during the cooling season (Fig. 6-a).

During the late cooling season, the opening ratio is 0.1–0.2 lower for sunny conditions than for cloudy ones for all humidity bins. This is inconsistent with results of the questionnaire survey in which they open windows because the weather is fine. Windows are not always open because of sunny weather but are open only for lower humidity when sunny only during the cooling season (Fig. 6-b).

Fig. 7 shows the ratio of air-conditioner use for indoor temperature bins. Differences according to weather are slight during the cooling season (Fig. 7-a).

During the late cooling season, the ratio of air-conditioner use is higher for all indoor temperature bins for cloudy weather, although the differences are small (Fig. 7-b).

Fig. 8 shows the ratio of air-conditioner use for indoor humidity bins. During the cooling season, for 13 g/kg' and 14 g/kg' of indoor humidity, the ratio of air-conditioner use is higher for cloudy conditions, but for 15 to 17 g/kg', the ratio is higher for sunny weather. The ratio has troughs for both sunny and cloudy weather. The results might reflect the fact that indoor humidity is kept lower by a higher ratio of air-conditioning use; it becomes higher by a lower ratio of air-conditioner use. That tendency is stronger for sunny weather (Fig. 8-a).

During the late cooling season, differences of air-conditioner use by weather for the same bins of indoor humidity are small. The ratio of air-conditioner use is higher for higher indoor humidity for cloudy weather, but the ratio does not increase along with indoor humidity for sunny weather (Fig. 8-b).

Fig. 9 shows the ratio of opening by weather for indoor temperature bins. During the cooling season, the ratio of opening is higher for sunny than for cloudy weather for the same bins of indoor temperature (Fig. 9-a).

During the late cooling season, the opening ratio is lower for sunny weather than for cloudy weather for indoor temperatures of 27°C and 28°C (Fig. 9-b). The ratio is lower for higher indoor temperatures both for sunny and cloudy weather, although the tendency is stronger for sunny weather. Fig. 7-b shows that the ratio of air-conditioner use is not so high for sunny conditions for indoor temperatures of 27°C and 28°C. These results suggest that indoor thermal conditions are comfortable with closed windows and without air conditioning when the indoor temperature is between 27°C and 28°C for sunny weather. However, for cloudy weather, windows tend to open for the same indoor temperature, although air conditioners are not running.

Fig. 10 shows the ratio of opening by weather for indoor humidity. During the cooling season, the difference of the ratio according to the weather is small (Fig. 10-a).

During the late cooling season, the ratio of opening is higher for cloudy weather for the same indoor humidity, but the difference is small during the cooling season (Fig. 10-b). Fig. 6-b shows that the ratio is higher for cloudy weather for the same outdoor humidity. For indoor humidity, the difference of the ratios between weather conditions is greater for higher indoor humidity bins, although the difference is almost uniform for outdoor humidity.

Conclusions

Effects of weather conditions on the relation between thermal control use and temperature or humidity in apartments were investigated during summer–autumn. Results show the following for the cooling season: 1) a) the ratio of air-conditioner use does not differ by weather for the same outdoor temperature; b) the ratio of opening, which is higher for sunny weather, does not differ by weather for the same outdoor temperature when the temperature is higher than 27°C; c) the ratio of opening, which is higher for sunny weather, does not differ by weather for the same outdoor humidity when the humidity is higher than 15 g/kg'; and d) the ratio of air-conditioner use does not differ by weather for the same indoor humidity. During the late cooling season, the following were found: 2) a) the ratio of air-conditioner use is higher for sunny weather when the outdoor temperature is higher than 21°C; b) the ratio of opening does not differ by weather for the same outdoor temperature; c) the ratio of opening for cloudy conditions is higher by 0.1–0.2 than for sunny for the same outdoor humidity; d) the ratio of air-conditioner use is higher for cloudy conditions for the same indoor temperature; and e) the ratio of opening is higher for cloudy conditions for the same indoor humidity. The difference between ratios of cloudy and sunny conditions is greater when the indoor humidity is higher.

An earlier questionnaire survey showed that people open windows because of fine weather, but results of this study clarified that windows are not always opened because of sunny weather; they are opened only for lower humidity. Windows are rather more likely to be opened for cloudy weather than for sunny weather, given equal humidity.

References

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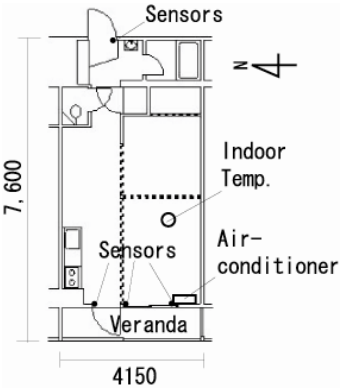


Fig. 1 Floor plan

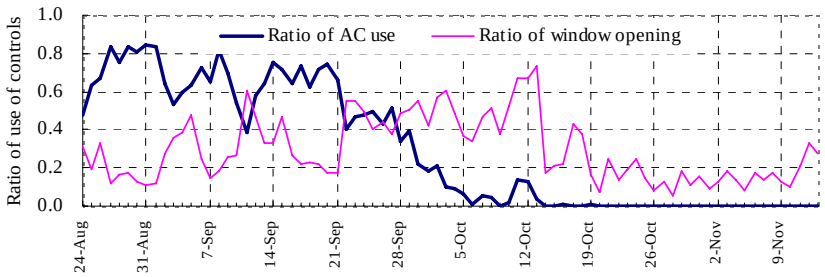
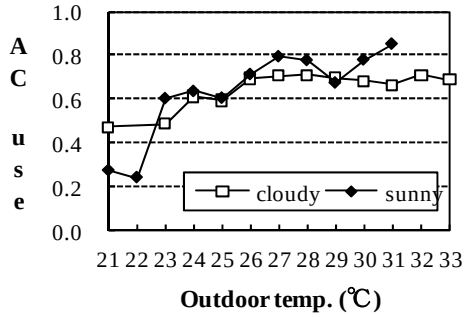
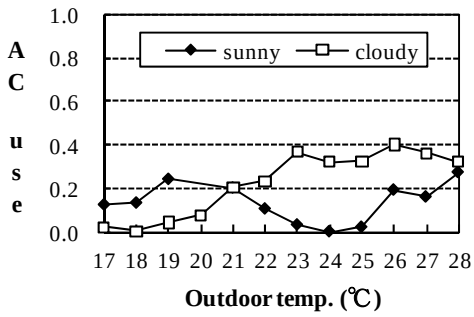


Fig.2 Daily mean ratio of AC use and window opening

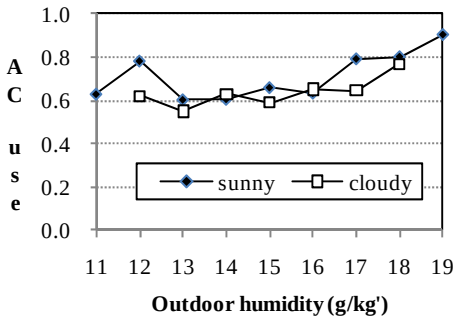


(a) Cooling season

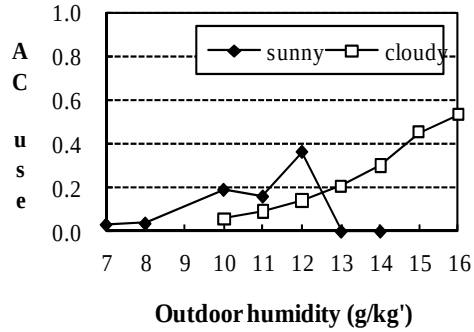


(b) Late cooling season

Fig.3 Outdoor temperature and ratio of AC use

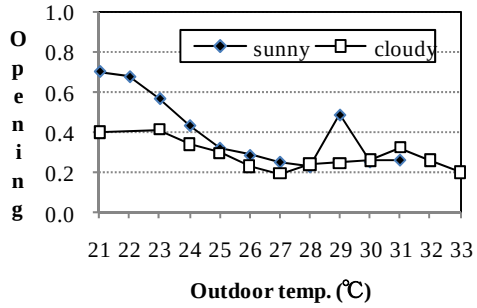


(a) Cooling season

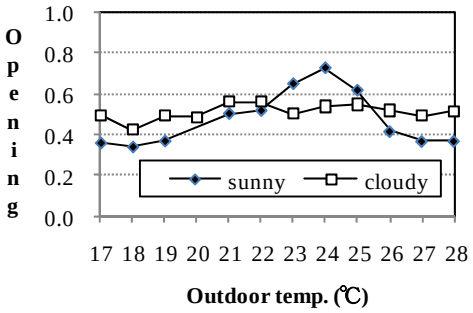


(b) Late cooling season

Fig.4 Outdoor humidity and ratio of AC use

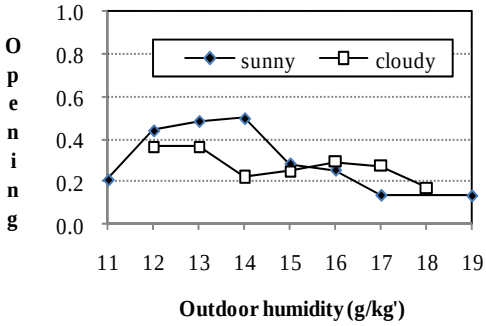


(a) Cooling season

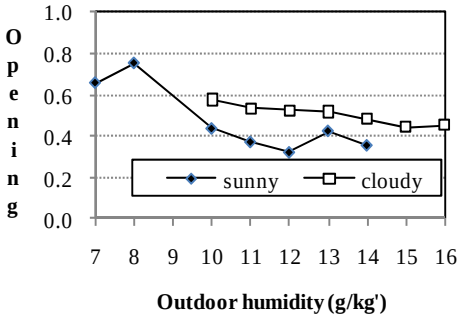


(b) Late cooling season

Fig.5 Outdoor temperature and ratio of opening

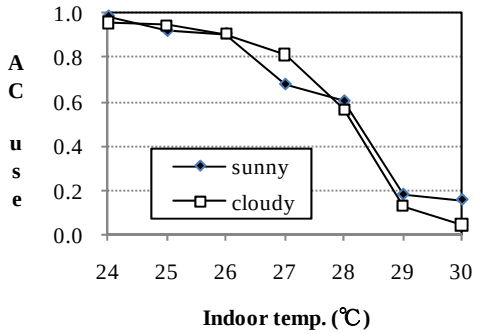


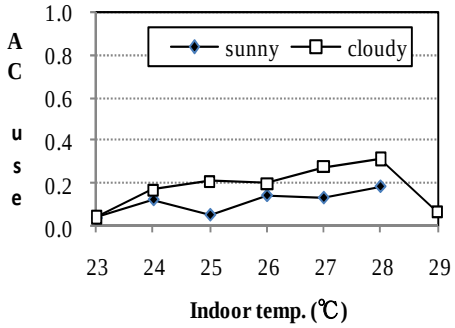
(a) Cooling season



(b) Late cooling season

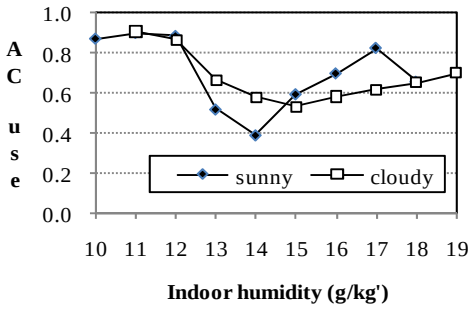
Fig.6 Outdoor humidity and ratio of opening



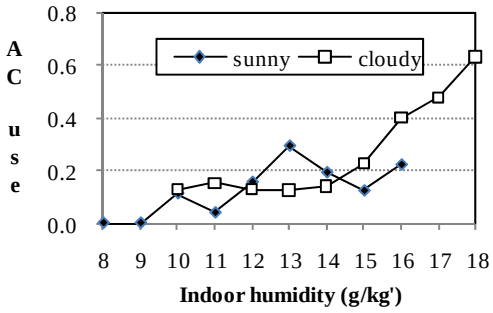


(a) Cooling season

Fig.7 Indoor temperature and ratio of AC use

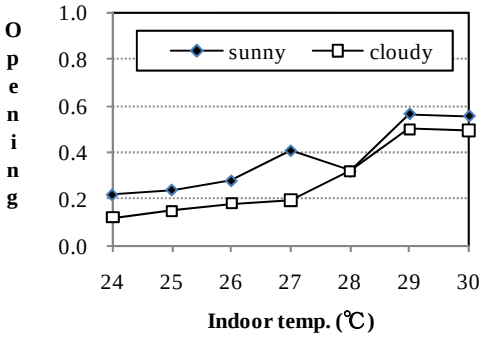


(a) Cooling season

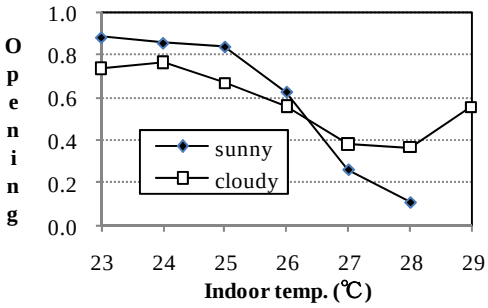


(b) Late cooling season

Fig.8 Indoor humidity and ratio of AC use

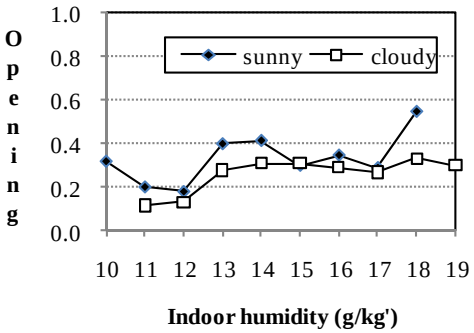


(a) Cooling season

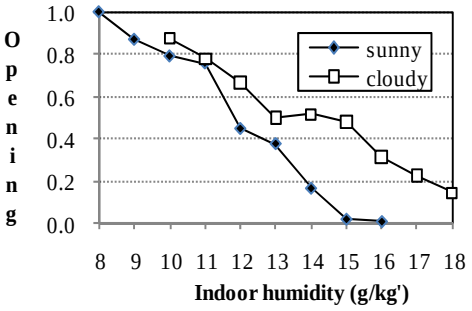


(b) Late cooling season

Fig.9 Indoor temperature and ratio of opening



(a) Cooling season



(b) Late cooling season

Fig.10 Indoor humidity and ratio of opening