Proceedings of 7th Windsor Conference: ***The changing context of comfort in an unpredictable world*** Cumberland Lodge, Windsor, UK, 12-15 April 2012. London: Network for Comfort and Energy Use in Buildings, http://nceub.org.uk

Effect of Air Movement in Housing during Japanese Summers

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Abstract

Previously, Kuno et al. conducted experiments and showed that the mean comfort votes of four female subjects were not uncomfortable when the room air temperature was 32°C and air movement by natural ventilation was more than 0.6 m/s. We conducted a chamber experiment in April 2011 using a device that produced uniform air movement. The speed of air movement was changed as requested by each subject. Mean values of final chosen air speed by six male subjects were 0.70 m/s at 32°C and 0.87 m/s at 34°C. In August 2011, we started a new experiment at two model houses. In the last summer experiment, comfort votes of twelve female subjects were not uncomfortable when the air temperature was 32–34.5°C and air movement by natural ventilation was more than 0.6 m/s. We consider that moderate and constant transpiration of moisture from the skin leads to a comfortable feeling for humans.

Keywords: thermal sensation, thermal comfort, air movement, hot environment

Introduction

In Japan, the thermal insulation and airtightness of houses have been improved for increased efficiency of air-conditioning systems. However, natural ventilation in summer has become more important and its usefulness needs to be publicized. Xu et al. (1996, 1999a, 1999b) and Kuno et al. (1997) conducted a chamber experiment and revealed the effect of air flow when subjects entered a room set at 28ºC or 30ºC after being in a room set at 34ºC. Ko et al. (2009, 2010) conducted experiments using subjects at a model house in Urayasu City, Japan for each season in a year. The area had a stable prevailing wind direction and the air flow in the living room moved across the subject's entire body. When the room air temperature was 32°C and air movement by natural ventilation was more than 0.6 m/s in the summer experiment, the mean comfort votes of four female subjects on a bipolar scale were not uncomfortable. This effect of natural ventilation exceeds that obtained from the theory of steady thermal conditions and it is more comfortable at the high temperature side of the thermal comfort range under the natural ventilation conditions in offices expanded

by ASHRAE. However, the model house was also visited by other guests, so the windows were shut and mechanical air conditioning was used at higher air temperatures, but they could not identify the thermal sensation and comfort of subjects when the room temperature exceeded 32°C. Therefore, we conducted the chamber experiment to assess the effect of natural ventilation using subjects, and then conducted an experiment at the model houses in Toyota City in 2011.

Methods

Experiment in a test chamber

Experiment period and test chamber: The chamber experiment was conducted in April 2011. Figure 1 shows the floor plan of the test chamber that has two rooms: one is a large room with a device that produces uniform movement of air over the subject's body and the other is a small room where the air is almost still. Figure 2 shows the device for air movement and the sitting conditions for the subject. The distance between the device and the subject's head was 1.25 m. The device draws in room air from the back side, adjusts it and supplies uniform air from an outlet measuring 1.5 × 1.5 m. The supply air temperature is the same as the room temperature.

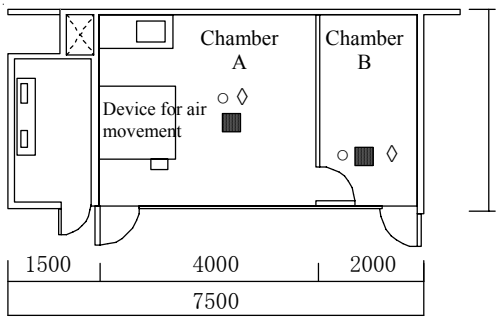

Fig. 1 Test chamber

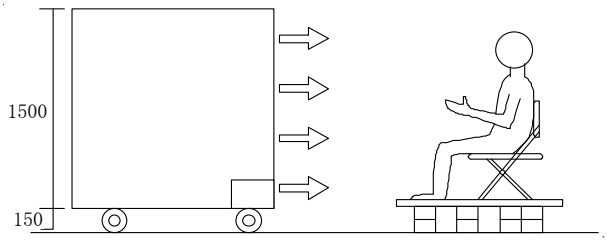

Fig. 2 Device for uniform air movement and sitting conditions for the subject

Experiment conditions and method: The room air temperature was set at 32°C or 34°C, and relative humidity was kept at around 50%. These conditions were the same in both rooms. First, the subjects changed their shirt to a prepared T-shirt and stayed in Chamber B without air movement for 30 min, and then moved to Chamber A with air movement of 0.5 m/s for 10 min. Then, the speed of air movement was changed in steps of 0.1 m/s according to each subject's request at the time of the psychological evaluation. After staying in Chamber A for 60 min, the requested speed of air movement was confirmed and the session was finished. In Chambers A and B, subjects were required to report the thermal sensation, thermal comfort and comfort of air movement on a 7-point bipolar scale every 5 or 10 min.

Subjects: The subjects were six male students, and the experiments were conducted in turn. Table 1 shows the physical characteristics of the subjects. The clothing of the subjects was lightweight for summer with a clothing insulation value of 0.44 clo.

Table 1 Physical characteristic of subjects in April 2011 experiment

	Age (years)	Height (m)	Weight (kg)	Body surface area (m^2)
32°C	23.1 ± 2.6	1.72 ± 0.03	60.2 ± 5.1	1.73 ± 0.08
34°C	23.1 ± 2.6	1.73 ± 0.04	59.7 ± 5.1	1.73 ± 0.08

Results: Figures 3 and 4 show the temporal change in thermal sensation and comfort, respectively. In Chamber B without air movement, the mean value of thermal sensation was hot and that of thermal comfort was uncomfortable even at the 32°C condition. After moving to Chamber A, where the air movement was 0.5 m/s, and staying there for 10 min, the mean values of thermal sensation and thermal comfort were slightly warm and slightly uncomfortable, respectively.

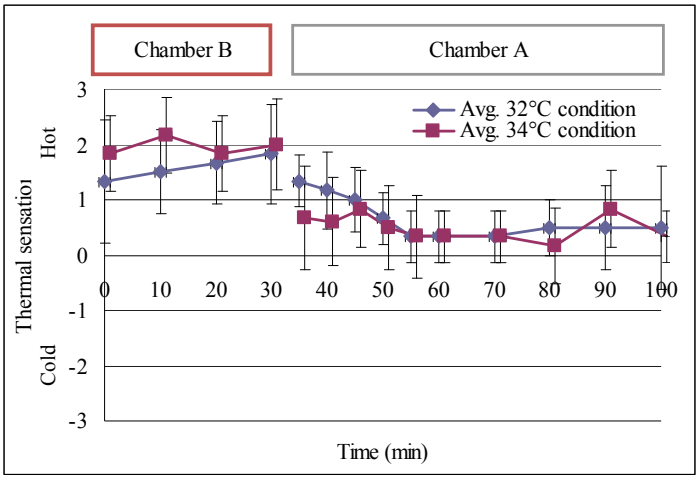

Fig. 3 Temporal change in thermal sensation

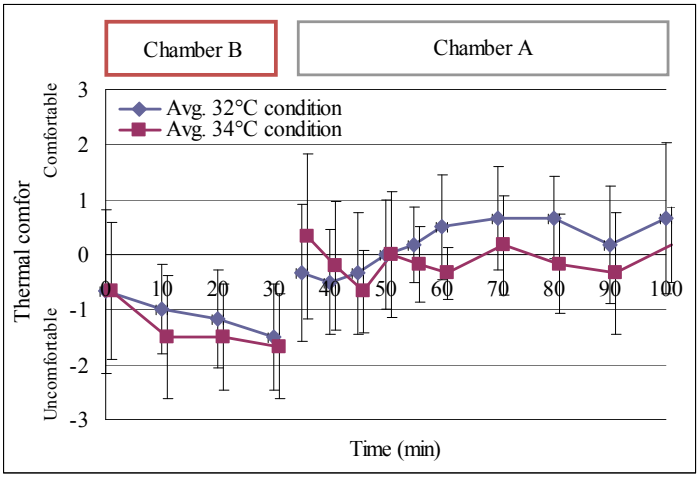

Fig. 4 Temporal change in thermal comfort

After 10 min in Chamber A, the speed of air movement was changed in steps of 0.1 m/s according to each subject's request at the time of the psychological evaluation. Figure 5 shows the temporal change in subjects' chosen air speed and Table 2 shows the final chosen air speed at the end of the experiment. Mean values of the final chosen air speed were 0.70 m/s at 32°C and 0.87 m/s at 34°C. At that time, the mean thermal sensation votes were near neutral and the mean comfort votes were not uncomfortable, as shown in Figs. 3 and 4.

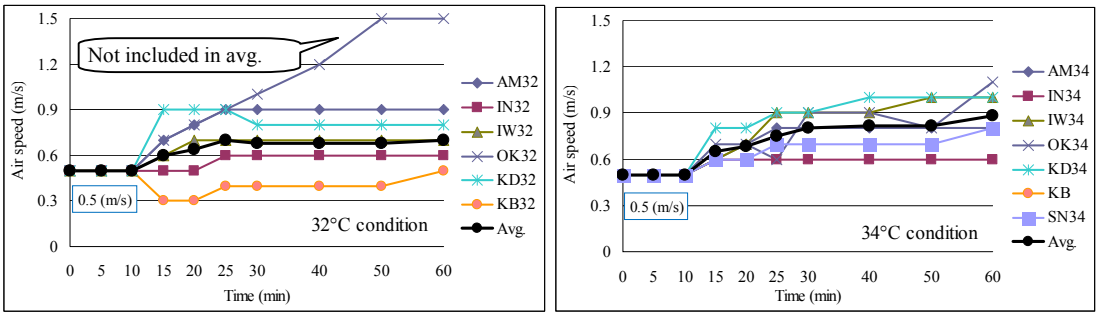

Fig. 5 Temporal change in subjects' chosen air speed

Table 2 Subjects' final chosen air speed at the end of experiment

Sub.	AM	IN	IW	OK	KD	KB	SN	Average
32°C	0.9	0.6	0.7	1.5	0.8	0.5	-	0.70*
34°C	0.8	0.6	1.0	1.1	1.0	-	0.7	0.87

*Average excluding subject OK

Experiment at model house

Experiment period and model house: In August 2011, we began a one-year experiment at two model houses in Toyota City, central Japan (Fig. 6). The floor plan and an exterior photograph of one of the model houses are shown in Figs. 7 and 8, respectively. This house is in a location with prevailing southwesterly winds in summer.

Fig. 6 Location of Toyota City

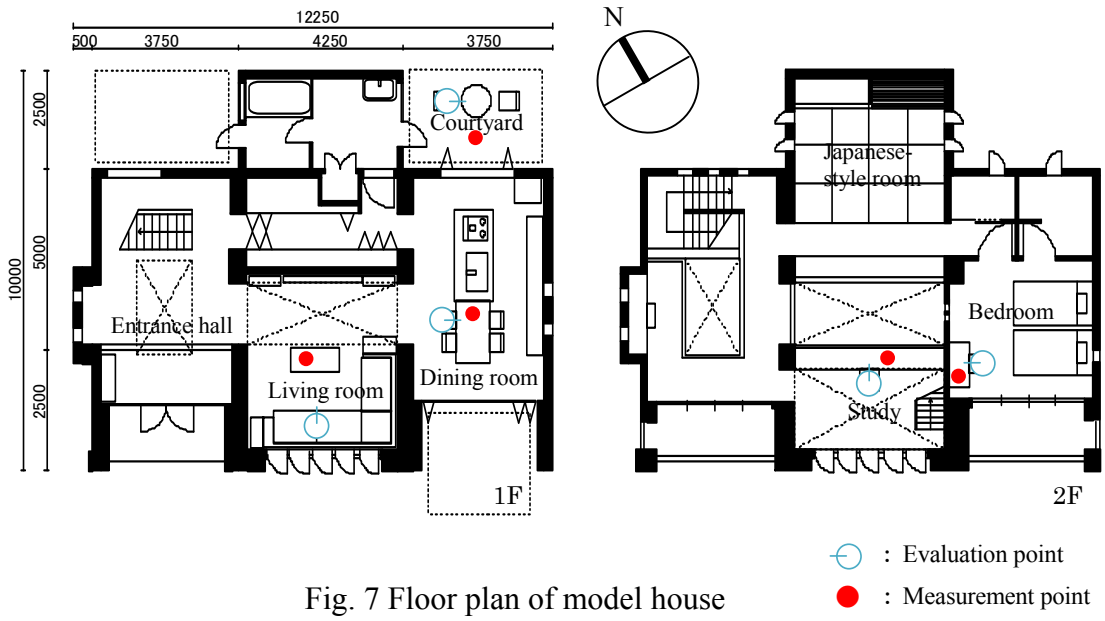

Fig. 7 Floor plan of model house

Fig. 8 Exterior of model house

Experiment conditions and method: The experiment was conducted in the morning (10:30–12:30) and in the afternoon (14:00–15:30). In this summer experiment, only natural ventilation was used in the morning sessions. Five evaluation points, as shown in Fig. 7, were prepared in the house. The subjects moved one by one to each point and reported their thermal sensation and comfort.

Subjects: The subjects were 12 female students. They were divided into four groups which participated in each session. Table 3 shows the physical characteristics of each group. The clo values were 0.43–0.51.

Table 3 Physical characteristics of subjects in August 2011 experiment

Group	Age (year)	Height (m)	Weight (kg)	Body surface area (m^2)	Clo value
g1	18.7±0.5	1.59±0.06	48.3±4.5	1.47±0.09	0.51±0.11
g2	18.7±0.9	1.54±0.07	47.7±8.1	1.43±0.15	0.45±0.10
g3	18.3±0.5	1.57±0.04	46.5±0.7	1.43±0.03	0.43±0.06
g4	20.0±0.9	1.57±0.05	46.0±2.9	1.43±0.07	0.49±0.07
Average	18.9±1.0	1.57±0.06	47.1±5.2	1.44±0.10	0.47±0.08

Results: Here, we report the measured results from the house shown in Figs. 7 and 8, as there was almost no wind in the other house. Figure 9 shows the relationship between thermal sensation votes and air temperature. Each plot shows the mean value for each group. Even though the mean thermal sensation votes were correlated to the air temperature, when the air temperature was 32–34.5°C and air movement speed was more than 0.6 m/s, the thermal sensation votes were between neutral and slightly warm.

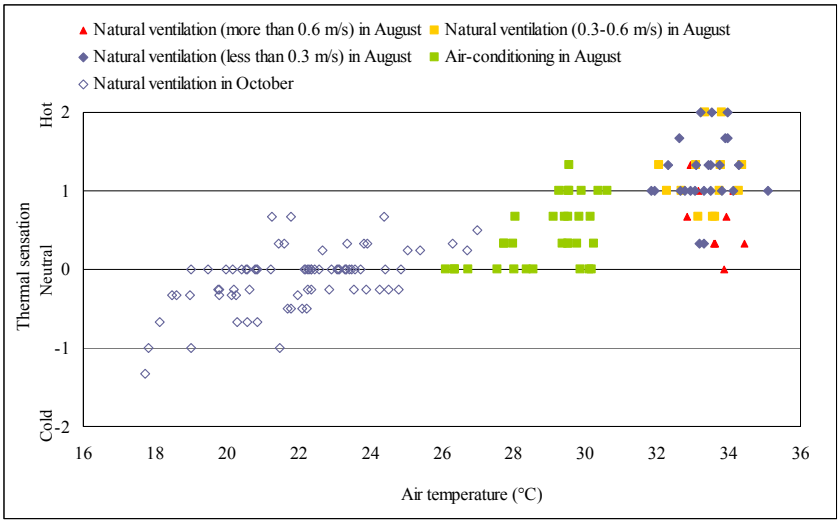

Fig. 9 Relationship between thermal sensation votes and air temperature

Figure 10 shows the relationship between thermal comfort votes and air temperature. When the air movement speed was more than 0.3 m/s, the mean thermal comfort votes were not uncomfortable but they became comfortable when the air movement speed was more than 0.6 m/s by natural ventilation, even though the air

temperature was 32–34.5°C. On the other hand, the air temperature was 26–30°C and thermal comfort votes were between slightly uncomfortable and comfortable when the air conditioning system was operated in the afternoon session. There was a difference in temperature of 4–6°C between the two conditions, but the range of thermal comfort votes was almost the same.

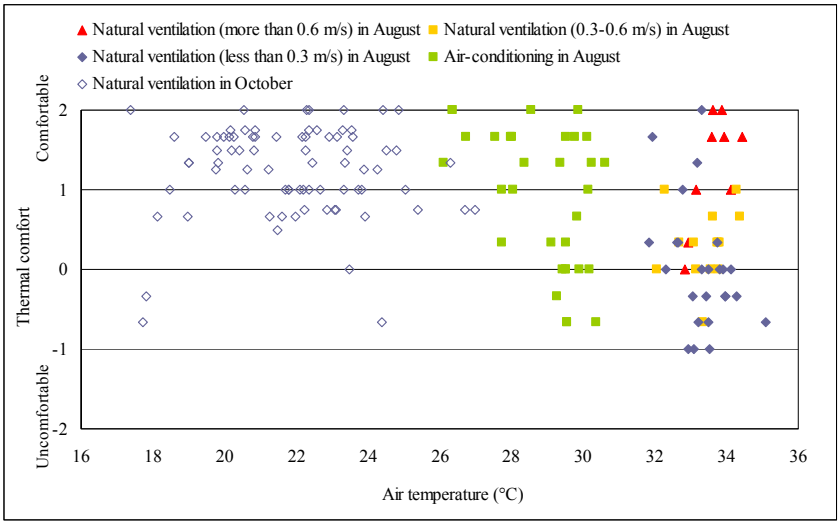

Fig. 10 Relationship between thermal comfort votes and air temperature

Figure 11 shows the rate of thermal comfort votes at each air movement speed range when the subjects felt the air movement. It is clear that 80% of the subjects cast comfort votes when the air movement speed was more than 0.6 m/s.

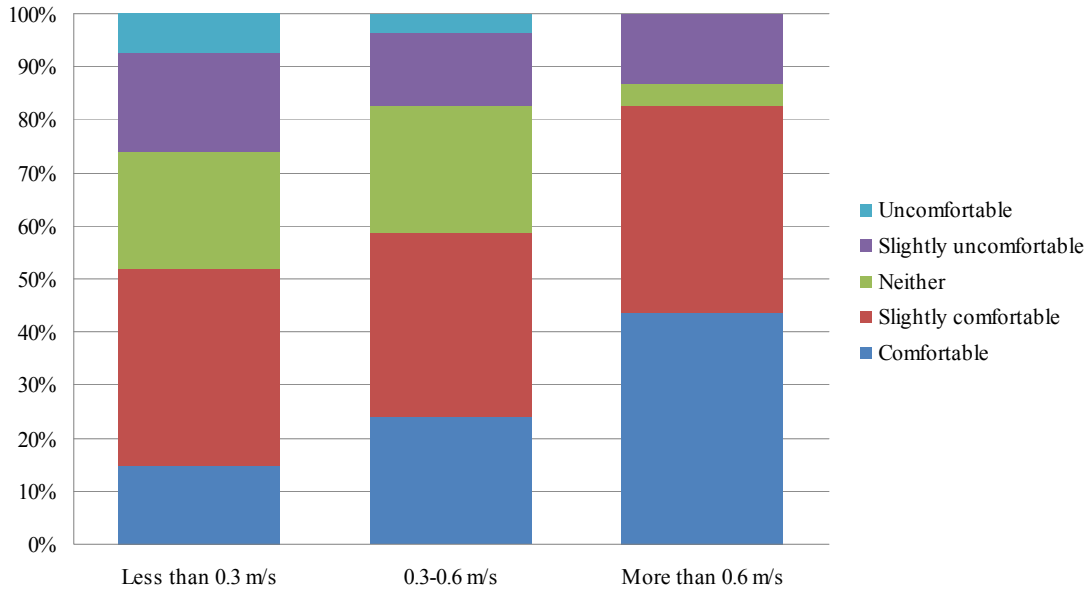

Fig. 11 Rate of thermal comfort votes at each air movement speed range

Discussion

In general, the neutral thermal condition is considered to be 25.5–26°C in SET* and SET* does not decrease to that condition when the air temperature is 32–34°C even if there is air movement. However, in the chamber experiment, the mean values of the subjects' final chosen air speed were 0.70 m/s at 32°C and 0.87 m/s at 34°C when the mean thermal sensation votes were near neutral and the mean comfort votes were not uncomfortable. This result at the 32°C condition is almost the same as that obtained in the field experiment by Ko et al. Furthermore, in the experiment at the model house in 2011, the thermal comfort votes of the twelve female subjects were not uncomfortable, even though the mean thermal sensation votes were slightly warm, when the air temperature was 32–34.5°C and air movement speed was more than 0.6 m/s. These conditions should be uncomfortable due to the increase in skin temperature according to the recent theory of heat transfer between the human body and the environment, but it is considered that the subjects felt thermal comfort from the wind at more than 0.6 m/s even under these conditions. This might be the effect of pleasantness explained by the two-dimensional thermal sensation model by Kuno et al. (1987, 1995). In the present series of experiments, we did not measure physiological values. Therefore, we cannot draw a precise conclusion, but we consider that moderate and constant transpiration of moisture from the skin leads to a comfortable feeling for humans.

Conclusions

We reported the results of the experiments conducted in 2011 at a test chamber and a model house. The subjects reported their thermal sensation and comfort under conditions of over 32°C air temperature with air movement. The following results were obtained.

1) In the chamber experiment, the speed of air movement was changed according to each subject's request at 32°C and 34°C air temperature. Mean values of the final chosen air speed by male subjects were 0.70 m/s at 32°C and 0.87 m/s at 34°C, and the mean thermal sensation votes were near neutral and the mean comfort votes were not uncomfortable at these air speeds.
2) In the experiment at the model house, the thermal comfort votes of female subjects were not uncomfortable, even though the mean thermal sensation votes were slightly warm, when the air temperature was 32–34.5°C and air movement speed was more than 0.6 m/s.
3) The subjects felt thermal comfort from wind of more than 0.6 m/s even at a temperature over 32°C. We consider that moderate and constant transpiration of moisture from the skin leads to a comfortable feeling for humans.

Acknowledgments

The experiment in a test chamber was carried out with the research support of the Hibi Science Foundation. The authors sincerely thank the Foundation and students of Nagoya University who served as subjects.

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