Proceedings of 8th Windsor Conference: ***Counting the Cost of Comfort in a changing world***
Cumberland Lodge, Windsor, UK, 10-13 April 2014. London: Network for Comfort and Energy Use in Buildings, http://nceub.org.uk

Survey on the thermal comfort and occupant behaviour in the bedrooms of Japanese houses

Hikaru Imagawa[1], Hom B Rijal [2]

[1]*Department of Environmental & Information Studies, Tokyo City University, Yokohama, Japan*
[2]*Department of Restoration Ecology & Built Environment, Tokyo City University, Yokohama, Japan*

[1]g1131026@tcu.ac.jp
[2]rijal@tcu.ac.jp

Abstract
In order to know the thermal comfort of bedrooms, we have measured the air temperature and relative humidity in the 27 bedrooms of 11 houses. We have also conducted a thermal comfort survey, quality of sleep and occupant behaviour survey with the residents. Residents are highly satisfied with the thermal condition of the houses, using various thermal adjustments such as fans, clothing modifications, etc.

Keywords: Bedroom; Thermal comfort; Occupant behaviour; Clothing insulation; Fan usage

1. Introduction
Basically, Japan is rich in four seasons with hot summer and cold winter. So it is important to provide a suitable thermal environment for each season. However, by considering the regional and seasonal variation of Japan, achieving thermal comfort is not easy task. In addition, there are also complex environmental conditions due to the various factors including global warming, thermal radiation from concrete pavement and heat generated from electrical/electronic equipment which has a direct impact on the indoor climate.

Sleeping is one of the most important human behaviour in the domestic residence. However, sleep disorder are one of the key issues in recent years. This might be related to the various environmental changes which are mentioned above. Sleep disorders involve not just thermal comfort but also declining performance after waking up and general health deterioration.

In order to clarify the thermal comfort in bedrooms, we have measured the air temperature, relative humidity and global temperature in the 27 bedrooms of 11 houses. We have also conducted a thermal comfort survey, quality of sleep and occupant behaviour survey to the residents.

2. Field Study
The measurements were conducted in 11 houses in the Kanto region in Japan (Tokyo, Kanagawa and Chiba). The measurements were performed from August 10 to October 3, 2013. The indoor temperature and relative humidity were measured in 10 minute intervals at the height of 110 cm above the floor level of each bedroom. The outdoor temperature was obtained from the nearest meteorological station. The thermal comfort survey was conducted "before the occupants went to bed" and "after getting up" (Table 1). We have collected 1271 thermal comfort votes from 28 residents.

Table 1. Questionnaire for thermal comfort survey

No.	Thermal sensation	Thermal preference	Overall comfort	Sleep depth
1	Very cold	Much warmer	Very uncomfortable	Very light
2	Cold	A bit warmer	Uncomfortable	Light
3	Slightly cold	No change	Slightly uncomfortable	Slightly light
4	Neutral (neither cold nor hot)	A bit cooler	Slightly comfortable	Slightly deep
5	Slightly hot	Much cooler	Comfortable	Deep
6	Hot		Very comfortable	Very deep
7	Very hot			

3. Results and discussion

In this survey, the data was divided into two modes: the FR mode (Free running), CL mode (Cooling by air conditioning).

3.1 Outdoor and indoor air temperature

The mean outdoor air temperature during the survey was 27.7 °C in summer and 23.5 °C in autumn. The mean outdoor air temperature was 25.4 °C during the voting.

Figure 1 shows mean indoor air temperature during the voting in the bedroom. The mean indoor air temperature "before going to bed" was 27.5 °C in FR mode and 27.3 °C in CL mode. The mean indoor air temperature when "after waking up" was 27.9 °C in FR mode and 26.4 °C n CL mode. The results showed that the bedroom temperature of the CL mode was lower than the FR mode.

There are no signification differences of mean indoor air temperature by mode "before going to bed", but there is a signification difference of mean indoor temperature by mode "after getting up/rising". The results showed that residents used air conditioning during their sleep.

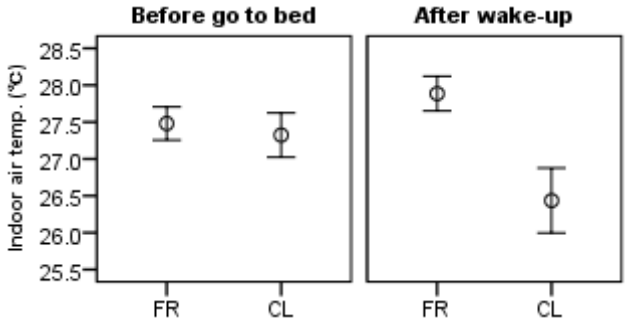

Figure 1 Mean indoor air temperature with 95% confidence interval

3.2 Evaluation of thermal comfort

3.2.1 Thermal sensations

Figure 2 shows distributions of thermal sensations, thermal preference and overall comfort. People generally voted “4 neutral” and “5 slightly warm” in FR mode and “4 neutral” in CL mode (Fig. 2(a)). There are many “3 no change”, “4 a bit cooler” votes in FR mode and “3 no change” votes in CL mode (Fig. 2 (b)). The results showed that most of votes are within the thermal comfort zone, and thus the sleeping environment is good. There are many “5 comfortable” and “4 slightly comfortable”, “3 slightly uncomfortable” votes in both modes. Even though people are feeling “neutral” and preferring “no change”, only a few people give the highest score for overall comfort.

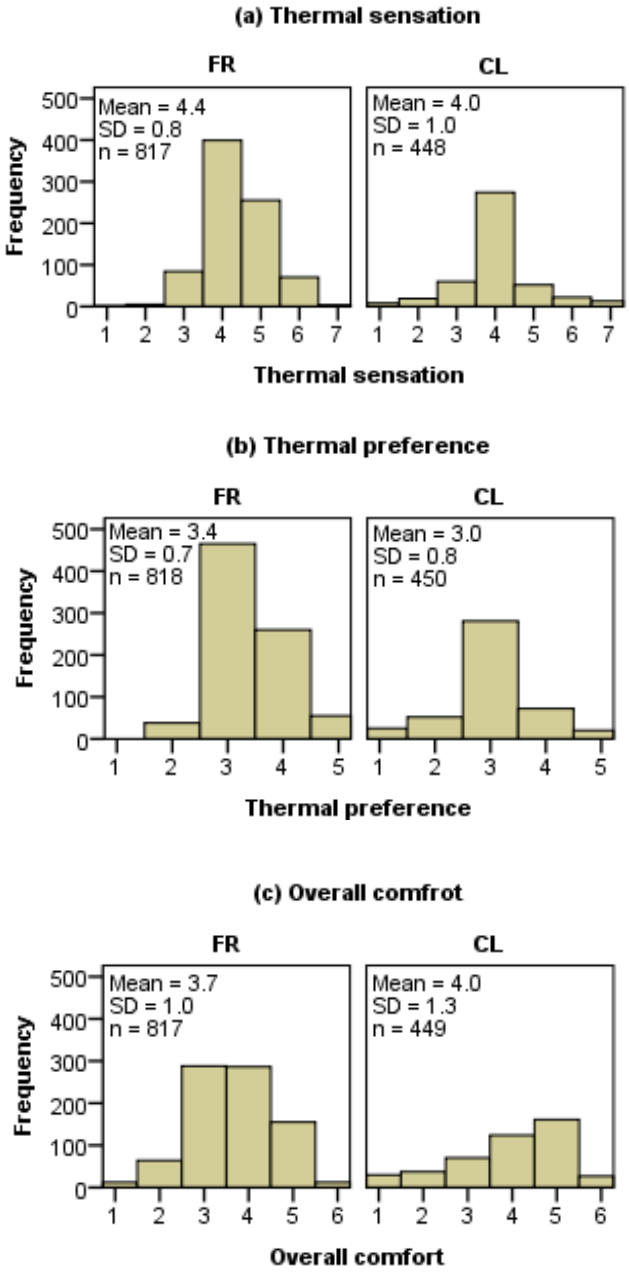

Figure 2 Distribution of thermal sensation, thermal preference and overall comfort

3.2.2 Relation between the thermal responses

Figure 3 shows the relation between the thermal preference and thermal sensation, overall comfort and thermal sensation, and overall comfort and thermal preference. On the whole, signification differences in FR mode are higher than CL mode. The reason might be that residents are considering the use of air conditioning (Fig. 3). The thermal preference and thermal sensation is correlated, and thus two scales are well-matched (Fig. 3(a)). When people felt "4 neutral" or "3 no change", most residents preferred "comfortable". However, there are only few votes for the category of "6 very comfortable" (Fig. 3(b)(c)).

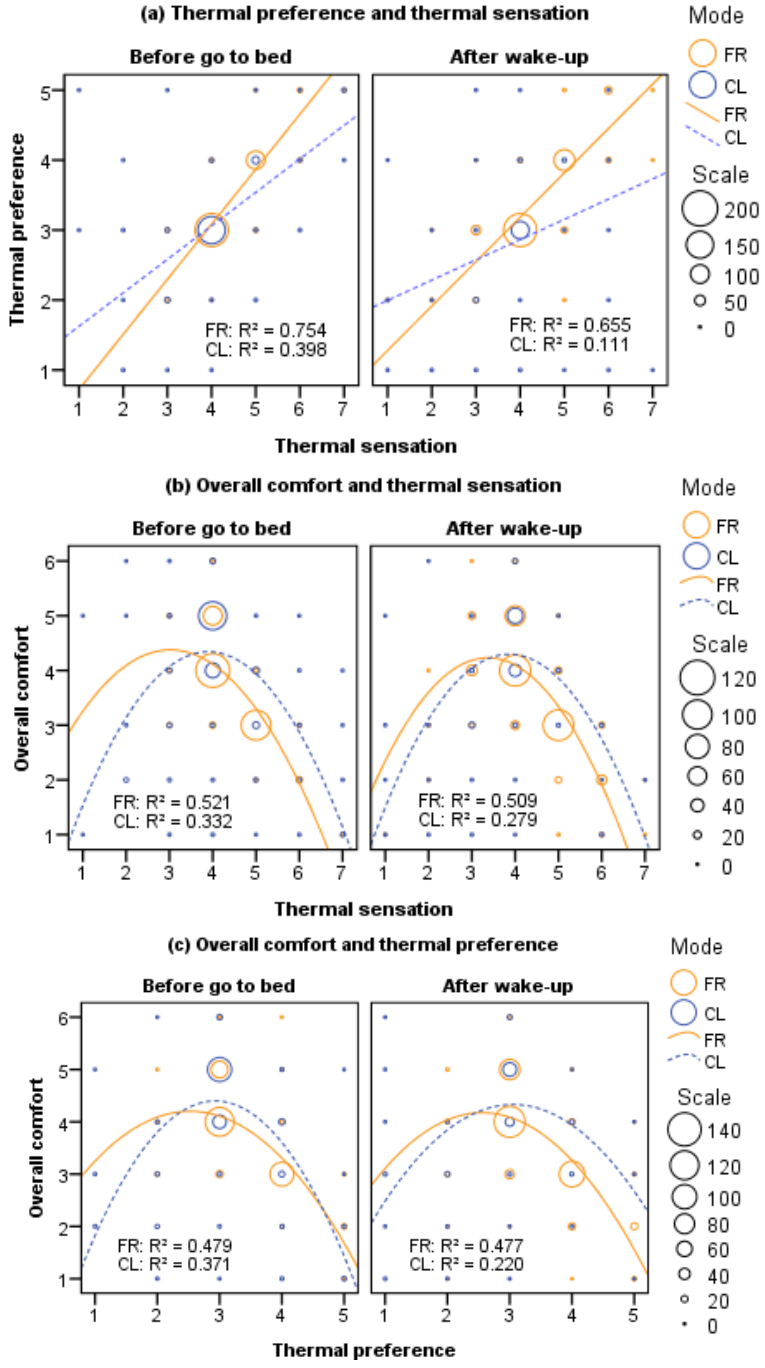

Figure 3 Relation between the thermal responses

3.2.3 Relation between the thermal responses and indoor air temperature

Figure 4 shows the relation between the thermal responses and indoor air temperature. The correlation coefficient of the FR mode is higher than the CL mode. In thermal sensation and thermal preference, the residents prefer "4 neutral" and "3 slightly cold", "3 no change", "4 a bit cooler" in FR mode. But in CL mode, the residents prefer only "4 neutral" and "3 no change". The reason might be that residents are considering the use of air conditioning (Fig. 4). It seems that residents feel comfortable at 27 °C indoor air temperature "before going to bed" in the FR mode.

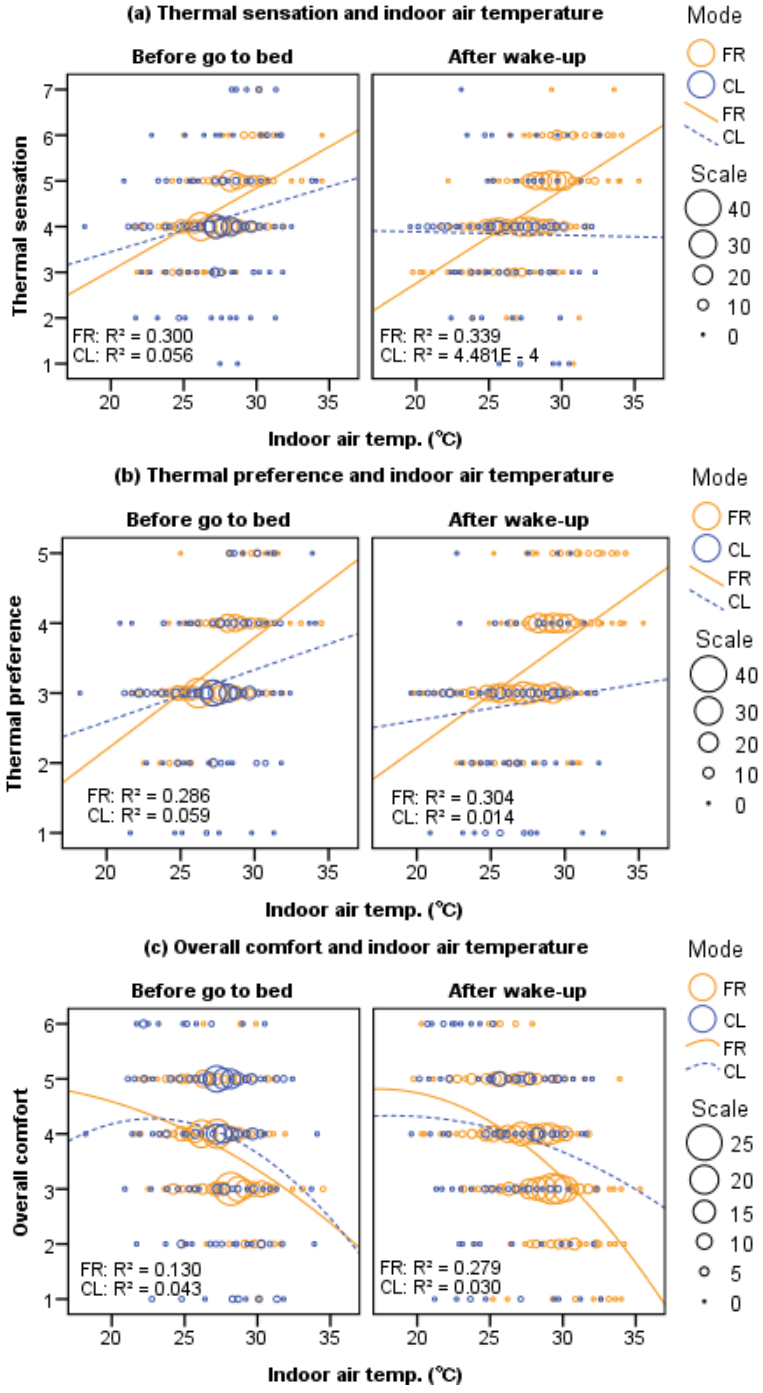

Figure 4 Relation between thermal responses and indoor air temperature

3.2.4 Prediction of comfort temperature by regression method

To predict the comfort temperature by the regression method, regression analysis of thermal sensation and indoor air temperature is conducted. The equation for CL mode is not statistically significant for "after waking up".

Before going to bed,

FR mode $C=0.181T_i-0.579$ (n=354, r=0.55, p<0.001) (1)

CL mode $C=0.095T_i-1.538$ (n=283, r=0.24, p<0.001) (2)

After waking up,

FR mode $C=0.204T_i-1.319$ (n=465, r=0.58, p<0.001) (3)

C: Thermal sensation vote, T_i: Indoor air temperature (°C), n: Number of samples, r: Correlation coefficient, p: Significance level of the regression coefficient.

When the comfort temperature is predicted by substituting "4 neutral" in the equations (1) to (3), it would be 25.2 °C in the FR mode, 25.9 °C in the CL mode for "before going to bed", and 26.1 °C in FR mode "after waking up". However, these comfort temperatures are lower than the mean indoor temperature when voted "4 neutral" (Table 2). Thus, the comfort temperature is predicted by Griffiths' method in the next section.

Table 2 Mean indoor air temperature when voting "4. neutral"

Items	Mode	n	T_{in} (°C)	SD(°C)
Before go to bed	FR	196	26.8	1.8
	CL	167	27.0	2.5
After wake-up	FR	203	27.0	2.1
	CL	107	26.1	3.0

n: Number of data, T_{in}: Mean indoor air temperature when residents vote "4 neutral" (°C), SD: Standard deviation (°C)

3.2.5 Prediction of comfort temperature by Griffiths' method

The comfort temperature is predicted by the Griffiths' method (Griffiths 1990, Nicol et al. 1994, Rijal et al. 2008).

$$T_c = T_i + (4 - C) / a \quad (4)$$

T_c: Comfort temperature, T_i: Indoor air temperature, C: Thermal sensation vote, a: Regression coefficient. In this research, a is assumed to be 0.5. The mean comfort temperatures by Griffiths' method for "before going to bed" are 26.7 °C in FR mode and 27.0 °C in CL mode. As for "after waking up", they are 27.2 °C in FR mode and 27.1 °C in CL mode respectively (Table 2). Since the mean comfort temperature of the Griffiths' method is comparable to the mean indoor air temperature when voted neutral (Table 3).

From these results, it can be said that the comfort temperature according to Griffiths' method is more appropriate than the regression method. The comfort temperature of this study was slightly lower than the recommended value of the Japanese government: 28 °C. The comfort temperature of this research is close to the previous research (Nishimura et al. 2011) (Table 4).

Table 3 Comfort temperature by Griffiths' method

Items	Mode	n	T_c (°C)	SD(°C)
Before go to bed	FR	354	26.7	1.8
	CL	280	27.0	2.9
After wake-up	FR	463	27.2	2.1
	CL	168	26.7	3.5

n: Number of data, T_c: Mean comfort temperature by Griffiths' method (°C), SD: Standard deviation (°C)

Table 4 Comfort temperature by Griffiths' method in previous research

Items	Mode	n	T_c (°C)	SD(°C)
Before go to bed	FR	436	27.1	2.4
	CL	584	27.2	2.4
After wake-up	FR	300	27.2	2.5
	CL	132	27.1	2.8

n: Number of data, T_c: Mean comfort temperature by Griffiths' method (°C), SD: Standard deviation (°C)

3.2.6 Relations between the thermal responses and hours of sleep

Figure 5(a) shows the relation between the thermal preference "after waking up" and hours of sleep. The correlation coefficient in CL mode is higher than in FR mode. This trend is different from relation between thermal responses and indoor air temperature. When people sleep more than 9 hours, they prefer "a bit warmer" or "much warmer". This might be due to the use of air conditioning in long period of time. Fig. 5 (b) shows the relation between the overall comfort and hours of sleep. The overall comfort is highest, when people sleep 5 to 9 hours in FR mode.

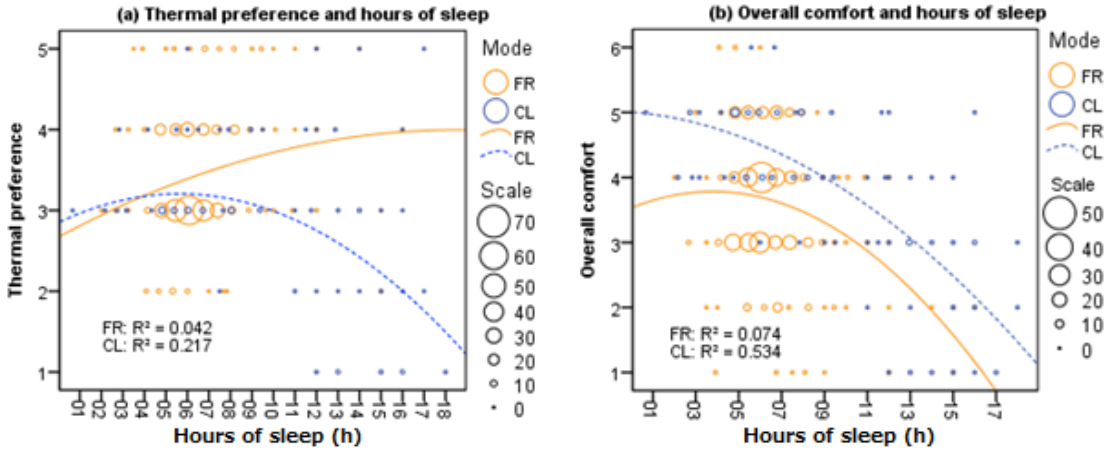

Figure 5 Relation between thermal responses and hours of sleep

3.2.7 Relation between the sleep depth and hours of sleep

Figure 6 shows the relation between the sleep depth and hours of sleep. The sleep depth is greatest when people sleep about 5~7 hours.

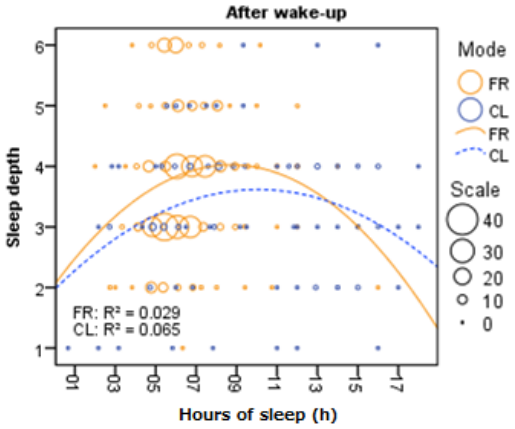

Figure 6 Relation between sleep depth and hours of sleep

3.3 Occupant behaviour

3.3.1 Cooling and fan usage

Table 4 shows the proportion of cooling and fan usage. The proportion of cooling usage is 61 % “before going to bed” and 30 % “after waking up” in summer. The proportion of fan usage is 51 % “before going to bed” and “after waking up” in summer. The cooling and fan usage is significantly decreased in the autumn. The results showed that people adjusted their sleeping environment by using various controls.

Table 4 Proportion of cooling and fan use

Items	Mode	Cooling		Fan usage	
		Summer	Autumn	Summer	Autumn
Before go to bed	Number of data	295	342	279	341
	Proportion (%)	61	30	51	22
After wake-up	Number of data	290	339	278	339
	Proportion (%)	30	24	51	18

3.3.2 Clothing insulation

The range of clothing insulation are 0.2 ~ 0.5 clo (Fig. 7). Most people were about 0.3 clo in this survey. The clothing insulation and indoor temperature is negatively correlated.

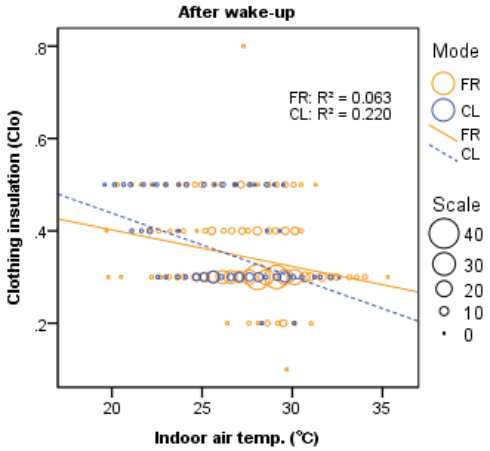

Figure 7 Relation between the clothing insulation and indoor air temperature

4. Conclusions

In this research, we conducted thermal measurements in the bedrooms and a thermal comfort survey of residents in the Kanto region of Japan. The following results were found:

1. The number of data of "neutral" vote was highest. The residents proved highly satisfied with the thermal environment of their bedrooms.
2. The comfort temperatures predicted by Griffiths' method "before going to bed" are 26.7 ~ 27.2 ℃.
3. The proportion of cooling and fan usage is significantly high in summer.
4. The clothing insulation and indoor temperature is negatively correlated.

References

1. Griffiths I.D. (1990), Thermal comfort in buildings with passive solar features: Field studies. Report to the Commission of the European Communities. EN3S-090 UK: University of Surrey Guildford.
2. Nicol F., Jamy G.N., Sykes O., Humphreys M., Roaf S., Hancock M. (1994), A survey of thermal comfort in Pakistan toward new indoor temperature standards, Oxford Brookes University, Oxford England.
3. Rijal H.B., Tuohy P., Humphreys M.A., Nicol J.F., Samuel A., Raja I.A., Clarke J. (2008), Development of adaptive algorithms for the operation of windows, fans and doors to predict thermal comfort and energy use in Pakistani buildings. ASHRAE Transactions, 114 (2): 555-573.
4. Ministry of the Environment, Government of Japan (2005), Result of "CoolBiz" campaign, http://www.env.go.jp/en/press/2005/1028a.html,
5. Nishimura M., Rijal H.B. (2011), Investigation of the comfort temperature and quality of sleep in the bedrooms, Summaries of Technical Papers of Annual Meeting AIJ, pp. 31-32.