Summer Comfort Temperature and Adaptation in Japanese Offices under the *Setusden* Conditions: A Field Study Report

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Thermal comfort Office buildings Adaptive model
Comfort temperature Thermal adaptation Field survey

1. Introduction

Japan's energy perspective underwent a paradigm shift after the 2011 Tsunami disaster. It put in place the '*setsuden*' (energy saving) campaign. This recommended minimum and maximum temperature settings for summer (28 °C) and winter (20 °C), without enough empirical evidence. Many large offices adhered to these, often running them in naturally ventilated (NV) mode by switching off from the air conditioning (AC) mode.

In the summer 2011, the *setsuden* efforts yielded 18% power savings in Tokyo [1]. Tanabe et al. [2] discussed in detail the occupant comfort satisfaction and productivity in offices operating under the *setsuden* conditions in 2011. In 2012, Indraganti et al. [3] clarified on the thermal comfort temperature under the *setsuden* in offices. Interestingly, the studies conducted during 2003 – 2005, i.e., prior to the Fukushima crisis observed no influence of the adaptive opportunity on the thermal perceptions across buildings [4]. Therefore, this paper highlights the comfort temperature and the user behavior in offices through a field study in Japan in summer 2012.

2. Methods: Field Survey under the *setsuden* Conditions

Tokyo lies on the humid subtropical climate zone. We conducted a thermal comfort field survey in 83 office spaces in four office buildings of The Tokyo University, in Tokyo during the months of July – September in 2012. The survey was scheduled to include the months of highest discomfort. Fig.1 shows the survey environments, the instrument details and typical female clothing ensembles. The buildings surveyed were typical office buildings found in Japan.

The first author conducted all the surveys directly using paper questionnaires. She interviewed 435 voluntary subjects and collected 2402 datasets (423 in NV and 1979 in AC), visiting each office twice a day with a minimum gap of two hours in between, for 29 days.

Table 1 Details of the thermal scales used [5]

Scale	Thermal Sensation	Thermal Preference	Thermal acceptance
3	Hot		
2	Warm	Much warmer	Unacceptable
1	Slightly Warm	A bit warmer	Acceptable
0	Neutral	No change	
-1	Slightly cool	A bit cooler	
-2	Cool	Much cooler	
-3	Cold		

The data consisted of thermal responses, simultaneous recordings of environmental measurements and her observations about the subject's clothing, activity and use of various

Figure 1. Typical survey environments, measurement setup and typical female clothing ensembles; (A) Omni-directional probe anemometer (Kanomax Climomaster 6531), (B) Thermo-hygro-CO_2 meter (TR-76Ui), (C) Globe thermometer (TR-52i)

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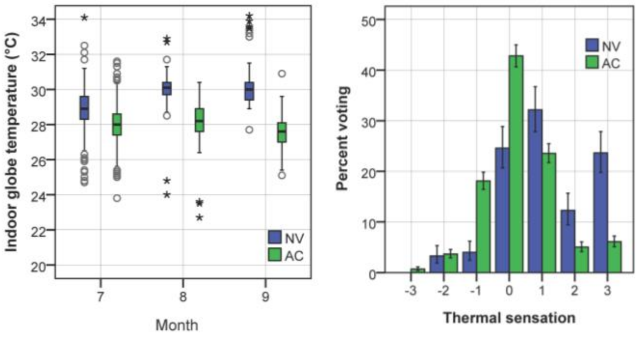
environmental controls. The controls observed were: windows, doors, blinds, curtains, common and personal fans, general and personal table lights and AC systems. We used calibrated high-precision digital instruments following the American Society of Heating Refrigeration and Air-conditioning Engineers (ASHRAE)'s Class-II protocols for field survey [5]. Table 1 shows the thermal sensation, preference and acceptability scales used in this survey.

The subject sample included 290 males. They are in the age group of 20 – 70 years. Men provided 51.2% of the data. About 22.1% the subjects were non-Japanese occupants. We estimated the clothing insulation of the subjects' ensembles using the summation method and standard lists [5]. Most of the subjects followed the '*coolbiz*' suggestions and were in light summer clothing (mean clo = 0.63 clo, SD = 0.08). We did not observe any significant gender or modal differences in the total clothing insulation. Metabolic activity changed from 0.7 Met (resting) to 2.0 Met (standing active work). A detailed account on the methods and the subject sample is in Indraganti et al. [3].

3 Results and Discussion

3.1 Thermal conditions and comfort responses



A B

Figure 3. Box-plots of outdoor and indoor globe temperatures and thermal sensation in NV and AC modes

Outdoor temperature during the three months of survey varied from 20.2 °C to 34.7 °C, with 29.7 °C as mean (standard deviation (SD) = 2.49 K). Outdoor humidity remained quite high throughout the survey averaging at 63.5% and ranged from 41% to 93%. The survey lasted from July 4 to September 11. Warm-humid summer conditions with intense discomfort prevailed throughout the survey.

We observed the offices switching between both NV and AC modes adaptively during our survey. Figure 2 shows the temporal variation in indoor globe temperature observed during the survey. It also shows the thermal sensation (TS) vote distribution in both NV and AC modes. Indoor globe temperature (T_g) was less variable compared to the outdoor temperature. In NV mode, mean T_g was 29.4 °C (N = 423, SD = 1.5 K) and in AC mode it was slightly lower averaging at 27.9 °C (N = 1979, SD = 1.2 K). Similarly, the mean indoor relative humidity was 52.6 % (SD = 6.4%) and 50.9 % (SD = 4.4%) in NV and AC modes respectively.

Air velocity in AC mode was slightly higher than NV (Fig. 3). The T_g data was ranked and divided in to ten bins of roughly equal size (deciles). Fig. 3 shows the mean of square root air velocity at 95% confidence interval (CI) in each of the T_g deciles for both NV and AC modes. The median of air velocity in AC mode was 0.21 m/s while it was 0.18 m/s in NV mode.

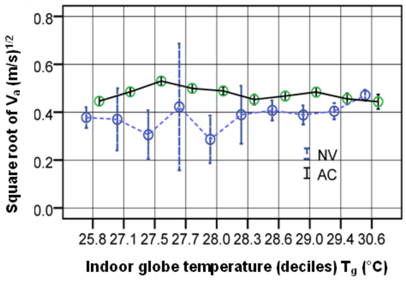


Figure 2. Change in indoor air speed (V_a) with T_g (deciles)

Thermal sensation (TS)

Thermal sensation was noted on the ASHRAE's seven-point scale. A significantly higher percentage of people voted on the warmer side of the scale in the NV mode than in AC mode at 95% CI (Fig. 2B). In NV mode only 69.1% were comfortable (voting between -1 to +1) and in AC mode 84.4%. About 31.9% and 65.3% felt 'neutral' sensation in NV and AC modes respectively. Mean sensation in NV mode was 1.17 (SD = 1.3) and AC mode was 0.24 (SD = 1.2).

Tanabe et al. noted greater variability in the mean sensation vote in Tokyo offices in a 2011 summer (July through August) study. They found it varying between -0.7 (SD = 1.1) to 2.0 (SD = 1.3). They noted the mean indoor air temperature varying between 25.3 °C (SD = 0.3 K) and 29 °C (SD = 0.9 K), while the relative humidity varied between 46 – 60% [2].

3.2 Linear regression analysis

Thermal sensation varied significantly with T_g during this study. However, we could not observe any modal difference in the T_g: TS relationship. Therefore, we applied the general linear regression model with mode as the fixed variable and obtained Eq. (1) and (2) for NV and AC modes (p<0.001) (Fig. 4):

NV Mode: $\mathbf{TS = 0.33\ T_g - 8.39}$ .... (1)

AC Mode: $\mathbf{TS = 0.33\ T_g - 8.85}$ .... (2)

Using these, we can note that the neutral temperature (when voting TS= 0) was 25.4 °C and 26.8 °C in NV and AC modes respectively. The slope of the equation explains the sensitivity of a population. It also indicates the perturbation needed in T_g for a unit shift in TS which in this case is 3 K. In offices in Jakarta, Karyano noted a similar sensitivity (slope 0.32 K^{-1}) [6]. Interestingly, subjects in Pakistan seemed to have displayed much wider adaptation, needing 6.5 K perturbation in T_g [7].

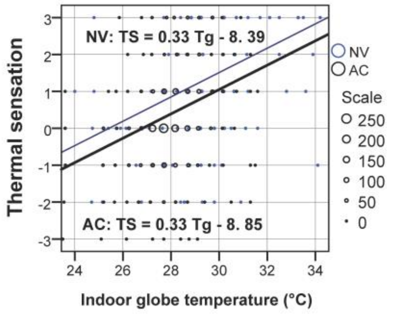


Figure 4. Change in globe temperatures with thermal sensation

Tokyo summer is very warm and humid. Therefore, to understand the combined effect of humidity on thermal sensation we conducted the multiple linear regression taking TS as the dependent variable and T_g and absolute humidity (W_v) (g_w/kg_{da}) as the independent variables. We obtained the Eq. (3) for NV mode. This equation and the coefficients are significant at $p<0.001$ ($r = 0.45$). Addition of air velocity did not improve the F-statistic much.

$$\textbf{NV Mode:} \quad \mathbf{TS = 0.27\,T_g + 0.22\,W_v - 9.71} \;\ldots\ldots\ldots\; (3)$$

This equation explains the equivalence of T_g and W_v and their effect on TS; i.e., 0.27/0.22 = 1.2 K variation in T_g has the same effect as a unit change in W_v on TS. It also shows the change needed in T_g for unit rise in TS as 1/0.27 or 3.7 K. We can observe that 1/0.22 or 4.5 g_w/Kg_{da} increase in W_v is needed for unit increase in TS. One of the regression coefficients in AC mode is not found to be significant at $p<0.001$.

3.3 Comfort temperature (T_{comf})

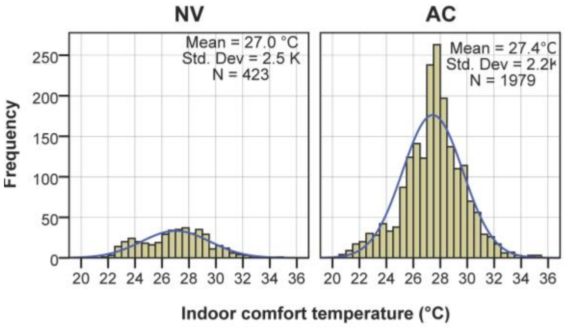


Figure 6. Distribution of comfort temperature

Many researchers used the Griffiths' method [6] to evaluate the comfort temperature from the field data [9,10], where a coefficient is assumed. We used 0.5 as the Griffiths' coefficient (G) that has massive field study basis [9]. Using the Eq. (4) we estimated T_{comf} for all the datasets in both the modes.

$$\mathbf{T_{comf} = T_g + (0\text{-}TS) / G} \;\ldots\ldots\ldots\ldots\ldots\; (4)$$

We noted the mean comfort temperature in NV mode to be 27 °C and 27.4 °C in AC mode. Higher comfort temperature in AC mode is perhaps due to the significantly lower absolute humidity when compared to the NV mode. In order to ascertain the effect of outdoor temperature on the indoor comfort temperature, we calculated the outdoor running mean temperature (T_{rm}) using Eq. (5), where, T_m is the outdoor daily mean temperature. T_{rm} varied from 22.6 – 30.0 °C while averaging at 25.9 °C in NV mode and 27.3 °C in AC mode.

$$\mathbf{T_{rm(tomorrow)} = 0.8\,T_{rm\,(yesterday)} + 0.2\,T_{m\,(today)}} \ldots\ldots\ldots\; (5)$$

3.4 The adaptive model

Indoor comfort temperature adaptively varied with the outdoor running mean temperature. We observed a statistically significant relationship between these two variables only in AC mode as shown in Eq. (6) and Fig.6.

$$\mathbf{T_{comf} \;=\; 0.10\,T_{rm} + 24.80} \;\ldots\ldots\ldots\ldots\ldots\mathbf{(6)}$$

This relationship is very close to that obtained in European offices in AC mode (slope = 0.09) [12]. It means that subjects in AC offices in Japan and Europe had similar adaptation levels. As can be seen in Fig. 6, much of the comfort data lies above the 28 °C limit of *setuden*. It is important to study how people have adapted in offices and found the higher temperatures comfortable, or the lack thereof when they expressed discomfort.

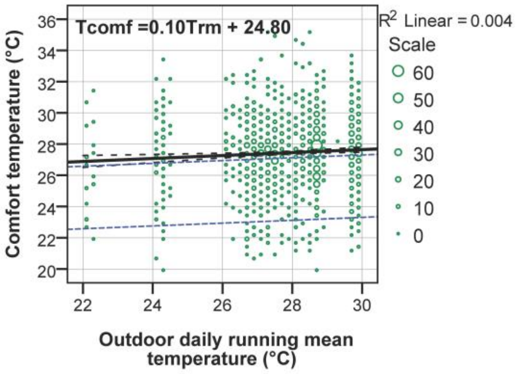


Figure 5. Relationship of comfort temperature with outdoor daily running mean temperature, superimposed with the upper and lower limits of a similar model from the CIBSE guide; Dotted lines are 95% CI of slope; Each point is a single dataset.

3.5 Thermal adaptation and impediments to adaptation

We observed many methods of adaptation in offices. Indraganti et al. described them in detail [3]. We show a few more examples here. The subjects have used lighter clothing, fans in both NV and AC modes and windows and doors in NV mode, adaptively as the temperatures increased (Fig. 7: left). The use of fan increased significantly with temperature. On an average, in 66% cases in NV mode and 78% cases in AC mode we noted that the fans were in use. In NV mode, the mean of door and window usage was 78% to 83% respectively.

Figure 7. (Left) Thermal adaptation and the use of elevated air speeds in offices; (Right) inoperable windows and balcony doors impede adaptation in offices

Perhaps as the buildings were all designed to function in AC mode always, most of the openings were not operable and many occupants had no access to fans. These were some of the major impediments to adaptation (Fig. 7: right).

4 Conclusions

A thermal comfort field study in offices in summer in Japan found the comfort temperatures to be 27.0 °C and 27.4 °C in NV and AC modes. We noted a significant adaptive relationship between the outdoor and indoor conditions the occupants found comfortable in AC mode, much similar to those of European offices. Subjects adopted many methods of adaptation to meet the challenge of warmer indoors (above the 28 °C of *setsuden*). Predominantly these were use of fans, operation of openings and clothing changes. Adaptation was also found to be seriously impeded by many architectural and non-thermal factors.

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