Effects of air movement and thermal radiation on thermally comfort range in urban districts

Noriko Umemiya[1], Masafumi Kawamoto[1], Takashi Tanaka[1], Ryoji Okura[1],
Motohiro Majima[2] , Rie Nakajima[2] and Harunori Yoshida[2]
[1] Osaka City University, Osaka, Japan
[2] Kyoto University, Kyoto Japan

1. INTRODUCTION

It has been said that thermal comfort ranges are wider in field surveys than in experimental rooms. Thermal environment and sensation were measured for pedestrians in urban districts including extreme heat and cold, strong radiation and air velocity. The relationships between the environment and thermal sensations were investigated when sensations of thermal comfort, air movement and radiation were different.

2. METHODS

2.1 MEASUREMENTS

Measurements of thermal environment and sensation of the pedestrians were carried out in seven urban districts in Kyoto and in two urban districts in Osaka. Air temperature, globe temperature, humidity, air velocity, solar irradiance and surface temperatures of the buildings and the streets were measured. Thermal sensation (-3: cold ～3: hot), sensation of thermal comfort (1: comfortable ～4: very uncomfortable), air movement (1:not perceivable～4:very perceivable) and thermal radiation (1:not perceivable～4:very perceivable) were measured.

2.2 OUT_SET* FOR URBAN CANYON

OUT_SET* (new standard effective temperature) proposed originally by R. de Dear was modified in Mean radiant temperature (T_{MRT}) to consider the long wave radiation $T_{MRT,L}$ from surrounding buildings as following equations. In the equations, f_p is effective area ratio, α_{cl} is albedo of clothing, $S\downarrow$ is direct solar irradiance, $D\downarrow$ is diffuse solar irradiance, α_{GND} is albedo of ground, F_{b_i} is form factor, T_{prt_i} is plane radiant temperature, σ is Stephan-Boltzman constant, ε is emmisibity, T_k is surface temperature, T_{sky} is sky surface temperature, $L\downarrow$ is long wave radiation.

Correspondence to: N.Umemiya, Osaka City Univ., Graduate School of Eng., 3-3-138 Sugimoto, Sumiyoshi-ku, Osaka city, 558-8585, Japan umemiya@arch.eng.osaka-cu.ac.jp

$$T_{MRT} = [\frac{f_p(1-\alpha_{cl})S\downarrow}{F_{eff}\sigma} + \frac{(1-\alpha_{cl})\{D\downarrow+(D\downarrow+S\downarrow)\alpha_{GND}\}}{\sigma} + T_{MRT,L}^4]^{0.25}$$

$$T_{MRT,L} = \sum F_{b\_i} \times T_{prt\_i}$$

$$\sigma\varepsilon T_{prt}^4 = \sum_{k=1}^{n-1} \sigma\varepsilon_k T_k^4 F_{p\_k} + \sigma\varepsilon_{sky} T_{sky}^4 F_{p\_sky}$$

$$L\downarrow = \sigma T_{sky}^4$$

3. RESULTS

Thermal sensation votes for 546 pedestrians (326 in summer, 120 in autumn and 100 in winter) in Osaka and for 546 pedestrians (180 in winter, 142 in spring and 224 in summer) in Kyoto were taken. Table 1 and 2 show the results of the measurements of thermal environment and sensations.

4. DISCUSSION

Relationships between OUT_SET* (SET* in short) and thermal sensations were analyzed. The regression lines of thermal sensation by SET* when pedestrians felt air movement were close to those when they did not. On the other hand, the pedestrians felt warmer when they felt thermal radiation in both cities, although the gradient of the regression line was steeper in Kyoto (Fig. 1). It can be said that SET* underestimated the sensation of thermal radiation outdoors, although it could reflect the sensation of air movement adequately.

If the data were separated into two groups according to the thermal comfort sensations, the gradient of the regression lines were steeper for thermally uncomfortable groups (“slightly uncomfortable” to “very uncomfortable”) than comfortable groups (Fig. 2). Squared correlation coefficients value, r^2, was 0.11 for Osaka and 0.15 for Kyoto for the comfortable groups, while the value was 0.26 for Osaka and 0.72 for Kyoto for the uncomfortable groups. This fact cannot be explained only by the inadequacy of SET* for wider range of thermal radiation outdoors. The relationship between thermal environment and thermal sensation could depend on whether the respondents feel comfortable or uncomfortable. Respondents in thermal comfort could be less sensitive to the thermal environment. It might be related to the wider ranges of comfort in field surveys.

5. CONCLUSION

The relationship between SET* and thermal sensation differed by thermal comfort sensation. The correlations were weak when pedestrians felt comfortable.

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Table 1. Thermal environment

City	Season		OUT SET* (℃)	ta (℃)	RH (%)	tg (℃)	MRT (℃)	Vel (m/s)	Irradiance (W/㎡)
Kyoto	Feb-March	mean	20.26	10.79	41.5	13.28	17.72	0.759	172.0
		sd	3.71	4.03	8.0	5.04	8.92	0.639	186.0
		min	13.90	5.10	21.5	5.70	5.80	0.012	14.0
		max	28.10	21.50	56.3	27.00	48.16	3.875	888.6
kyoto	May	mean	29.52	24.63	34.3	29.56	38.27	0.936	531.1
		sd	2.51	2.48	8.7	3.84	10.50	0.479	298.2
		min	25.20	20.20	17.6	22.60	23.90	0.020	14.4
		max	35.00	28.90	51.1	39.10	67.50	1.960	938.3
Kyoto	August	mean	34.58	31.44	46.3	34.73	41.41	0.799	268.8
		sd	2.16	1.60	4.1	3.78	9.70	0.366	263.1
		min	31.40	28.80	36.8	29.50	29.80	0.130	1.5
		max	42.20	36.40	59.8	46.60	77.50	1.710	924.0
Osaka	July-Sep	mean	31.92	30.55	53.4	32.31	36.10	1.042	213.0
		sd	2.77	2.86	9.5	4.31	12.54	0.707	253.7
		min	25.90	24.80	34.0	25.40	-5.60	0.000	8.1
		max	39.30	37.10	72.0	46.60	83.00	3.710	993.1
Osaka	October	mean	31.33	25.35	46.0	31.13	40.26	0.567	269.9
		sd	4.90	1.76	5.6	6.78	15.47	0.330	258.3
		min	21.20	20.40	39.0	21.10	22.70	0.000	5.6
		max	39.90	28.20	63.0	44.70	79.50	1.300	803.1
Osaka	January	mean	26.03	9.69	38.2	12.16	17.43	0.889	179.5
		sd	4.72	1.27	5.5	3.10	8.80	0.427	217.6
		min	18.00	6.70	32.0	7.70	8.40	0.190	11.9
		max	33.30	12.20	51.0	22.00	51.30	2.410	698.1

Table 2. Thermal sensation

City	Season		Sensation					
			Thermal	Comf	Air.mov	radiation	Humudity	Sweat
Kyoto	Feb-March	mean	-1.29	1.72	2.16	1.36	-0.22	1.15
		sd	1.79	0.81	0.82	0.64	1.04	0.41
		range	-3 ～3	1～4	1～4	1～4	-2～3	1～3
kyoto	May	mean	1.02	1.33	2.39	2.43	-0.77	1.43
		sd	1.60	0.57	0.84	0.94	1.15	0.63
		range	-3 ～3	1～4	1～4	1～4	-3～2	1～3
Kyoto	August	mean	1.68	2.00	2.42	2.15	1.34	2.09
		sd	1.53	0.77	0.77	1.01	1.20	0.74
		range	-2～3	1～4	1～4	1～4	-3～3	1～4
Osaka	July-Sep	mean	2.07	2.26	2.25	1.90	1.17	2.09
		sd	1.38	0.83	0.84	0.99	1.17	0.88
		range	-3 ～3	1～4	1～4	1～4	-3～2	1～4
Osaka	October	mean	1.25	1.47	2.16	1.94	-0.70	1.62
		sd	1.30	0.62	0.77	0.96	0.99	0.74
		range	-2～3	1～4	1～4	1～4	-3～2	1～4
Osaka	January	mean	-0.47	1.70	2.19	1.56	-0.21	1.11
		sd	1.81	0.77	0.81	0.83	1.03	0.35
		range	-3 ～3	1～4	1～4	1～4	-2～2	1～4

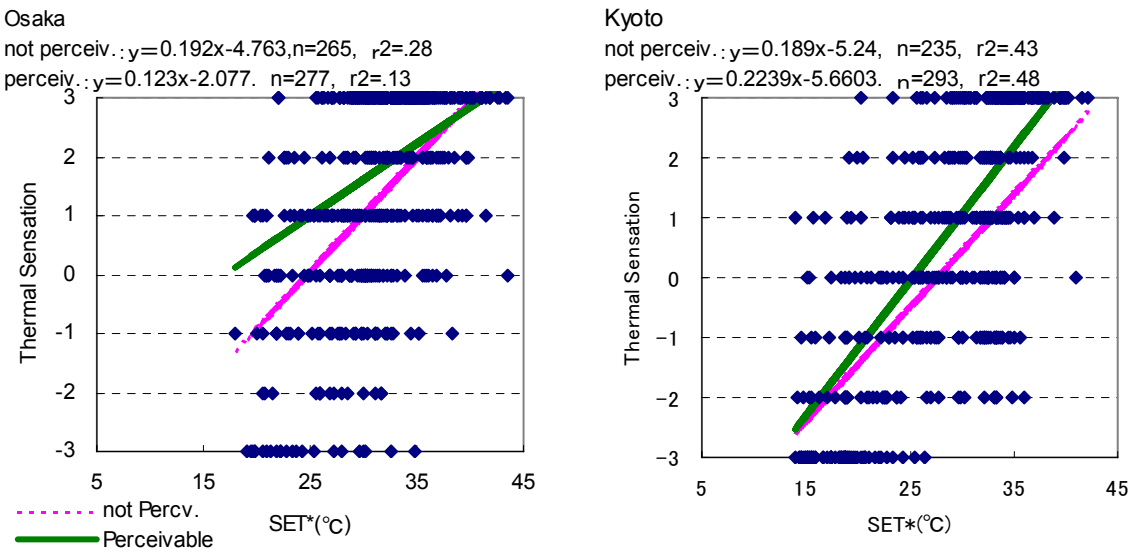

Fig. 1. Relationships between SET* and thermal sensation for different sensation of radiation

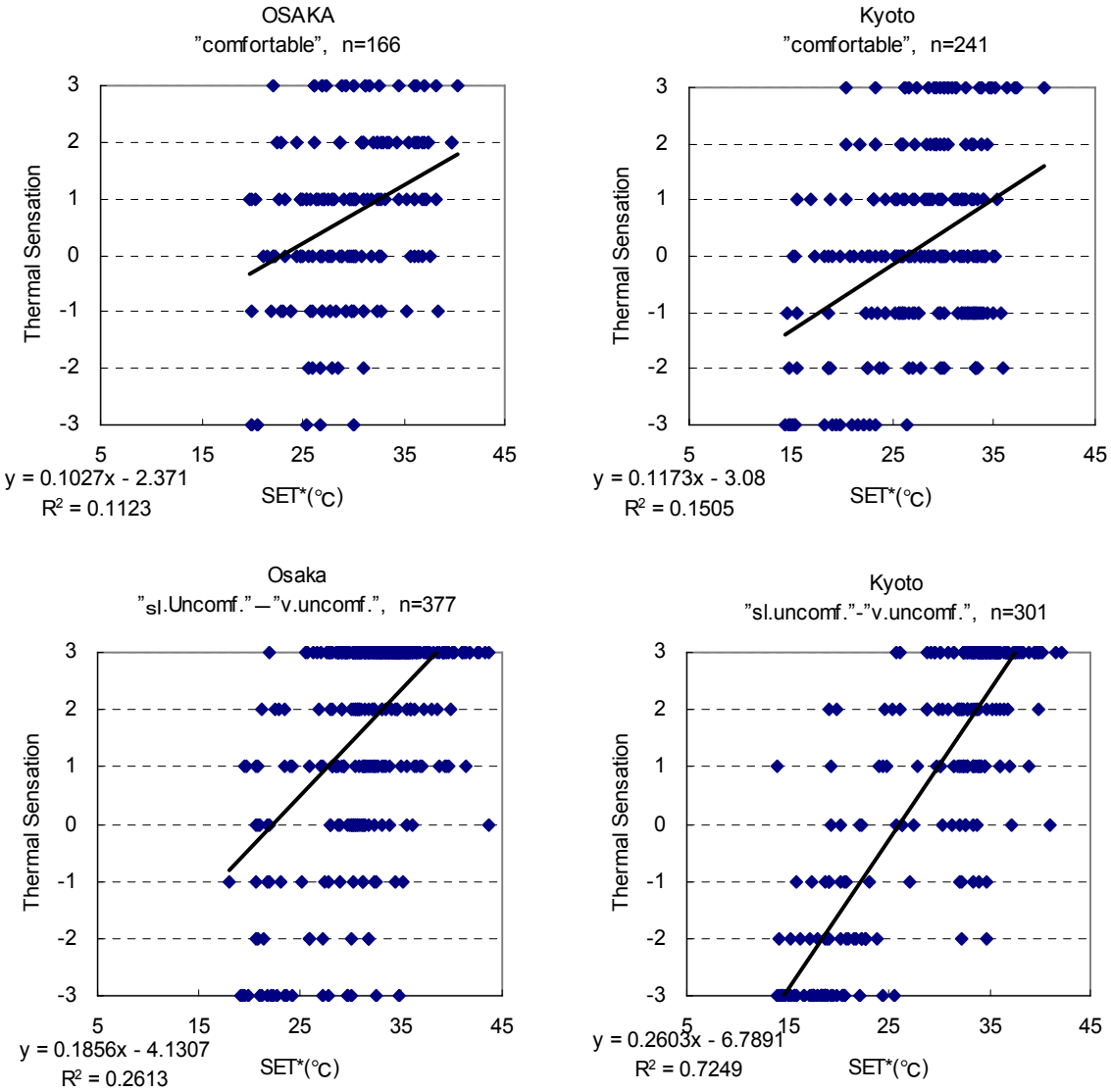

Fig. 2. Relationships between SET* and thermal sensation for different comfort sensation