# Thermal diary—records of temperature exposures during a 24-h period

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## ABSTRACT

This paper documents people's comfort during a 24-h period of typical daily life, immediately followed by a standard climate chamber experiment. The objective of this study is to determine the influence of outdoor weather, expectation, adaptive behaviours and perceptions of comfort on indoor comfort. The surveys and measurements took place in August 2002 in Seoul, Korea, and Yokohama, Japan, with 52 subjects carrying small, portable data loggers to record temperatures for a 24-h period prior to entering a controlled climate chamber. This paper will discuss the preliminary results found for the first half of the experiment and a full paper will follow with subsequent analyses performed from the climate chamber results. Subjects spend more than 90% of their day indoors. During a 24-h period, subjects were exposed to temperatures ranges of 15.6–37.4ºC in Yokohama and 16.5–33.8ºC in Seoul. Sudden temperature changes (more than 5ºC difference for 10 min) were recorded more than 3.5 times during the 24-h period. In both countries subjects were more sensitive to temperature drops than temperature increases.

## INTRODUCTION

Indoor environments are controlled by HVAC systems to create comfortable and stable conditions in all seasons. However, in our daily lives, we walk in and out of buildings and various modes of transportation many times in a day, often exposing us to great temperature fluctuations between indoor and outdoor environments. This persistent and irregular exposure to temperature fluctuations has the possibility of influencing comfort sensations and creating undesirable health effects. The literature revealed no information regarding how people feel towards temperature fluctuations during their daily lives. In this paper we examined temperature fluctuations and thermal comfort throughout a 24-h period of typical daily life in Seoul, Korea, and Yokohama, Japan. Perceptions of comfort might differ between countries because of economic status and life style—just a few of the factors that will influence indoor comfort. In considering outdoor temperatures in the context of our built environments, this research contributes a small piece of the puzzle in designing healthier environments for people.

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## METHODOLOGY

Surveys and measurement took place in Yokohama, Japan, during 6–9 August and in Seoul, Korea, during 20–23 August. Twenty-six university students from each university (Yokohama National University and Yonsei University) voluntarily participated in this study; 17 males and 9 females volunteered in Yokohama, and 13 males and 13 females volunteered in Seoul. Each subject carried (Figure 1) a small portable Espec, RS-11data logger (Figure 2) set to record temperatures and relative humidity during a 24-h period and were asked to complete a Thermal Diary of thermal sensations, using the ASHRAE seven-point scale as they moved about in their daily life. Subjects documented their thermal sensation and activity level each time they moved into another space. Air temperature and relative humidity were recorded per 1 min. An aluminium foil bell with holes shielded the temperature sensor to prevent direct solar radiation. Each subject came to the university a day before the experiment to receive instruction on how to complete the Thermal Diary and how to take care of the data logger. The Thermal Diary contained three parts: (a) preliminary questions about adaptive behaviours and attitudes, where they obtain weather information, how they make clothing decisions, air conditioner use at home; (b) survey to complete during the 24-h period; and (c) a post-test survey following the 24-h period that asked questions about comfort prior to entering the environmental control chamber.

**Figure 1** A subject with a data logger.

**Figure 2** Data loggers (Espec, RS-11).

## RESULTS

### Weather in Japan and Korea

The climate of Japan in most of the major cities, including Tokyo and Yokohama at a latitude 38°N, is temperate to sub-tropic and consists of four seasons. Yokohama's mean temperature in August during 30 years (1971–2000) is 26.4ºC with associated humidity of 78%. The climate of Korea is also characterized by four distinct seasons with striking contrasts between the winter and summer. Seoul's mean temperature in August during 30 years (1971–2000) is 25.4ºC with associated humidity of 77.4%. Table 1 shows local weather station information during experiment. The highest daily outdoor temperature during experiment was 35ºC in

Yokohama and 29ºC in Seoul, and lowest temperatures was 26.8ºC and 19.8ºC, respectively. Yokohama was hotter than Seoul during experiment, which is fairly typical for the season, particularly because there were periods of rain in Seoul.

**Table 1** Weather information

| | | Outdoor temperature | | | RH | | | Outdoor temperature | | | RH |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Date | Average | Highest | Lowest | % | | Date | Average | Highest | Lowest | % |
| Yokohama | 2002/8/6 | 30.1 | 35.0 | 26.8 | 66.0 | Seoul | 2002/8/20 | 24.5 | 29.1 | 19.8 | 59.5 |
| | 2002/8/7 | 29.9 | 34.2 | 27.0 | 64.0 | | 2002/8/21 | 24.5 | 28.6 | 21.8 | 72.8 |
| | 2002/8/8 | 29.3 | 34.0 | 27.0 | 63.0 | | 2002/8/22 | 22.8 | 23.8 | 21.5 | 86.6 |
| | 2002/8/9 | 29.1 | 32.5 | 26.8 | 65.0 | | 2002/8/23 | 24.8 | 27.0 | 22.4 | 84.9 |

**Adaptive Behaviours and Attitudes**

The following section provides a summary of the responses to the preliminary survey given to the subjects on various factors related to perception of comfort.

*Where do you check your weather?*

Most subjects find information about the next day's weather from the television (84.6% Yokohama, 57.7% Seoul). The Internet and cell phones are the second most popular source of information in Yokohama, and the Internet, newspaper, and no check in Seoul (Table 2). Interestingly, 7.7% (Yokohama) and 15.4% (Seoul) of the people do not check the weather status at all, which means a small percentage of the population possibly does not prepare for inclement weather

*What is the most influential factor for your clothing selection?*

The highest percentages showed weather in Japan (50%) and fashion in Korea (46.2%) influenced student responses.

**Table 2** Weather information source

| | Yokohama | | Seoul | |
|---|---|---|---|---|
| | sample number | /26 | sample number | /26 |
| 1. TV | 22 | **84.6%** | 15 | **57.7%** |
| 2. Intenet | 7 | 26.9% | 4 | 15.4% |
| 3. radio | 1 | 3.8% | 2 | 7.7% |
| 4. direct observation | 0 | 0.0% | 1 | 3.8% |
| 5. newspaper | 1 | 3.8% | 4 | 15.4% |
| 6. telephone | 4 | 15.4% | 1 | 3.8% |
| 7. don't check | 2 | 7.7% | 4 | 15.4% |
| 8. other | 0 | 0.0% | 1 | 3.8% |
| total | 37 | - | 32 | - |

*Do you have air-conditioning at home? If so, how approximately how many hours a day do you use air-conditioning?*

Almost all subjects (92.3%) in Yokohama have an air conditioner at home and use air-conditioning 5–8 h a day; contrasted with 61.5% of the subjects with air conditioning at home in Korea, using it less than 4 h per day. These results could be due to the economic difference between Japanese and Korean students and/or the weather of experiment day, with cooler conditions in Korea during the experiment.

*Clothing worn during the experiment*

CLO values were calculated from the surveys using insulation values from ISO 7730 (1994). Although there were large differences in outdoor temperatures between Japan and Korea, no significant differences of CLO value were seen (Table 3). We can draw the assumption that fashion was a determining factor during this season particularly since cooler temperatures were measured during the experiment in Korea, where we would expect to see higher CLO values. A cool season study might reveal differences in CLO because of adaptation and expectation.

**Table 3** CLO value of students' clothes

| frequency distribution | Yokohama | | Seoul | |
|---|---|---|---|---|
| | sample number | | sample number | |
| 0.27-0.35 | 6 | 23.1% | 8 | **30.8%** |
| 0.35-0.43 | 6 | 23.1% | 6 | 23.1% |
| 0.43-0.51 | 10 | **38.5%** | 8 | **30.8%** |
| 0.51-0.59 | 3 | 11.5% | 3 | 11.5% |
| 0.59+ | 1 | 3.8% | 1 | 3.8% |
| total | 26 | 100.0% | 26 | 100.0% |

**Time Spent in Indoors and Outdoors**

Results in both countries show virtually the same amount of time spent indoors (Figure 3). Subjects spent more than 90% of the day indoors (transportation vehicles were considered indoor environments). Although the length of time spent indoors may be influenced by hot weather or the fact that it was summer vacation (lots of students napping), these results corroborate earlier research (Shiotsu *et al.*, 1998).

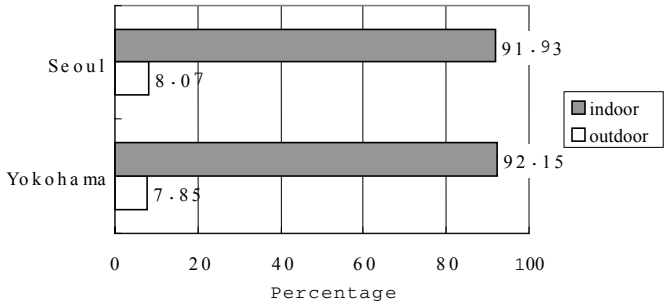


**Figure 3** Time to spend in indoor and outdoor.

**Temperature Exposures**

One data logger failed to record temperatures, so 51 subjects' data were analysed for the 24-h survey period.

*Distribution of temperature exposures*

The temperature exposures range from 15.6 to 37.4ºC in Yokohama and from 16.5 to 33.8ºC in Korea with median values of 28.0 and 26.0°C, respectively. Mean temperatures were 28.3°C in Yokohama and 26.3°C in Seoul (Figure 4). Distribution shape shows different point. Seoul's data are narrow and concentrated on 26.0–26.5°C, but in the case of Yokohama, distribution shape is wider and peak value is small.

*The highest and lowest temperature exposure*

In Seoul, the highest temperature exposure was 33.8°C (outdoors, midday) and the lowest temperature was 15.6ºC (outdoors, night-time). In Yokohama, the highest temperature was 37.4ºC (outdoors, midday) and the lowest temperature was 16.5ºC (indoors-home, night-time).

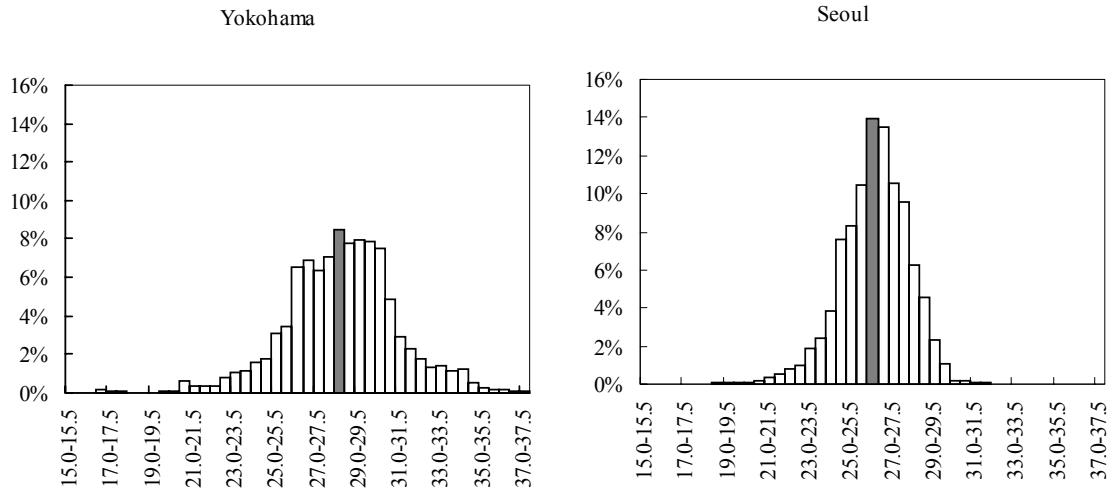


**Figure 4** Distribution of exposed temperature.

*Sudden temperature changes*

Compared to cold shock or heat shock which means a large step temperature change, we use the term 'sudden temperature change' as a large ramp change over a relatively short time. Taking into consideration the lag time of the sensor, we calculated how many times a subject encountered sudden temperature changes in which there were more than a 5ºC change during 10 min. These sudden temperature changes encountered by subjects during the 24-h period were approximately 4 times in Seoul and 3.6 times in Yokohama. That means people feel sudden temperature change more than 3.5 times during 24 h. Five of the 51 subjects encountered these sudden temperature changes more than 10 times during the 24-h period.

Figure 5 shows how many times of sudden temperature changes were encountered by subjects. To show this tendency clearly, we clipped data from –2 degree to 2 degrees. Data of Yokohama shows many more and larger changes than Seoul. This has a relationship with the wide temperature exposures shown in Figure 4.

*Thermal sensation during 24-h period*

Figure 6 shows how subjects felt whenever they moved into different spaces during the 24-h period. Thermal sensation votes of –1 and –2 (slightly cool and cool) showed an overall higher percentage than votes for warmer thermal sensations +1 or +2 (slightly warm, warm). In Figure 5, we can see the percentages of temperature drop/increase are not so different, and even though temperature increase occurred more often in Japan. From the comparison of Figures 5 and 6, we can see subjects responded to temperature drop more sensitively than temperature increases. Thermal sensation votes of +3 (hot) in Japan were remarkably higher than Korean votes. This is because of the hotter weather in Yokohama during the experiment. There is a possibility that the contrast of temperatures between outdoors and indoors made

subjects feel that the outdoor environments were even more uncomfortable, and therefore cast +3 votes on the thermal sensation scale.

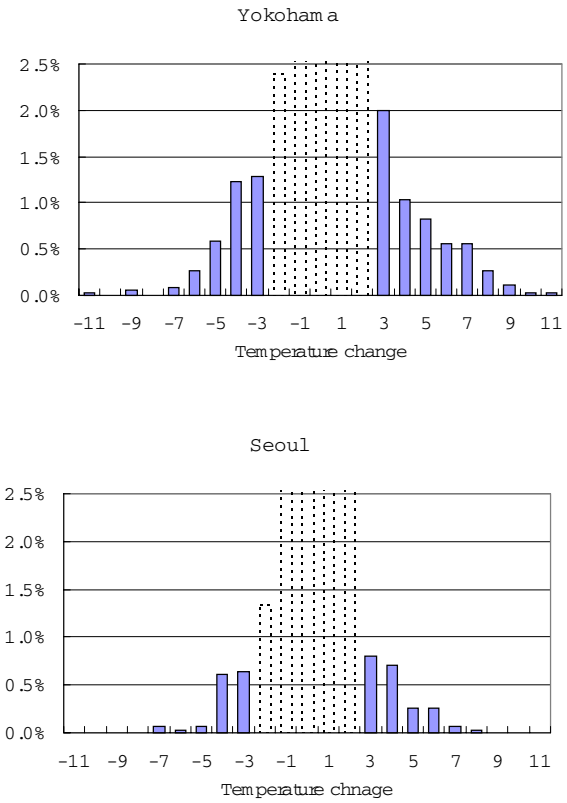


**Figure 5** Sudden temperature change.

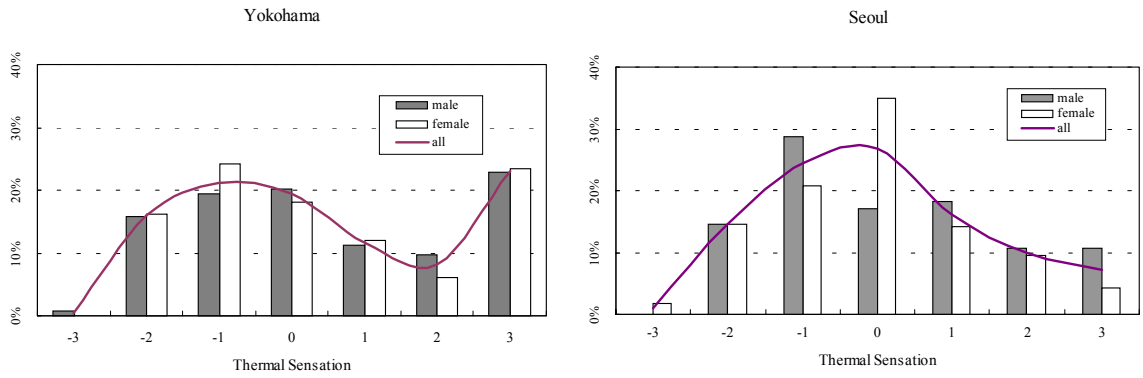


**Figure 6** Thermal sensation distribution during 24-h period.

## CONCLUSION

The weather during this study created a wide range of temperatures that subjects encountered and experienced during the 24-h test period.. This contrasts with the narrow range of comfort zone requirements that HVAC systems produce for indoor comfort, which has relatively no relationship to outdoor temperature fluctuations. Subjects in this experiment were exposed to approximately 22ºC ranges of temperatures during a 24-h period. Such a wide temperature fluctuation has the potential to create undesirable health effects and acclimatization problems. Perceptions of comfort are strongly associated with selection of clothing for imminent weather conditions and fluctuating and contrasting temperatures. The more we adapt to air-

conditioned environments as the standard of living, the stronger the discomfort we will feel with contrasting hot, outdoor weather. As a result, we might even spend even more time indoors.

## REFERENCES

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