

Measurement of Regional Evaporation Rate from Skin Surface by Evaporimeter

Soon Ja PARK and Teruko TAMURA

Department of Clothing Hygiene, Faculty of Home Economics, Bunka Women's University

The present study was conducted to confirm the validity of an evaporimeter and its measuring condition prior to applying it to the field of clothing physiology, especially for measuring the amount and distribution of the evaporation rate over the human body surface. After calibration of the evaporimeter according to the manufacture's specifications, it was checked for its response time and the comparative assessments of the evaporation rate from the skin. The quantitative examination of the evaporation rate in both in vitro water loss and in vivo the evaporation rate from the human skin, clarified that the observed values of evaporation rate were lower than water loss or weight loss of the human body. Although the evaporimeter is a useful device to measure the evaporation rate at regional parts of the human body under natural condition, an additional calibration by an actual in vitro measured water loss should be adopted for the accurate assessments of the evaporation rate.

(Ann. Physiol. Anthropol. 11(4): 417-423, 1992)

Key words : Evaporation rate from the skin surface, evaporimeter, Response time, Calibration

Water loss from the body surface by insensible and sensible perspiration plays a momentous role in controlling the thermoregulation by discharging body heat. Sweating is transferred from the skin surface to the outer environment through clothing, in the form of moisture or liquid water, and the clothing acts as a barrier against them. Therefore, it should be basically important for studying or designing comfortable fabrics as well as the construction of clothing from a standpoint of physiological anthropology to examine the amount and the distribution of the evaporation rate over the human body.

Perspiration is measured by recording the body weight loss. This gravimetric method is, however, limited to investigating the evaporation rate of the whole body. Over the last decades there has been a general trend of making local measurements of the evaporation from small skin areas (Herzman, 1957 ;

Kuno, 1956). Some methods using capsules were developed for measuring water discharge from a regional skin area. These methods using capsules are unventilated or ventilated but both may measure the evaporation rate under different climatic conditions inside the capsules. This disturbance of the environmental condition by capsule is a problem for measuring the evaporation rate under natural conditions. To solve this problem, an evaporimeter was developed by Nilsson (1977) for clinical use and laboratory work in 1970's. This method is based on the vapour pressure gradient in the air layer immediately adjacent to the skin. If the vapour pressure distribution in this layer is known, the amount of water evaporated per unit time and area can be calculated. In a steady state, the evaporation rate is stationary and hence, the vapour pressure gradient is approximately constant. Consequently this gradient can be estimated by calculating the difference

between the vapour pressure measured at two separate points located on a line perpendicular to the evaporative surface in the zone of diffusion, that is, above 10mm from the body surface. The actual vapour pressure at each point is calculated as a product of the relative humidity and the saturated vapour pressure. Therefore, the rate of evaporation is also proportional to this difference. The actual feature of the evaporimeter is shown in Fig. 1.

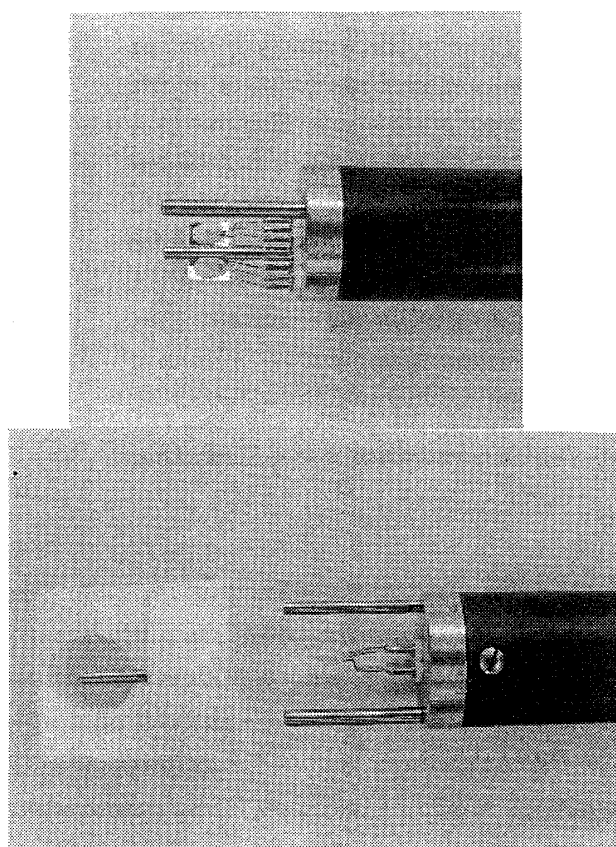


Fig. 1 The arrangement of relative humidity sensors and thermistors.

It is pointed out by Nilsson (1977) that evaporimeter has merits including the following seven points: 1) gives accurate results 2) has a high sensitivity 3) has a short response time 4) permits continuous as well as intermittent measurements 5) has only minimal influence on the rate of natural evaporation from the skin surface. 6) is easy to handle 7) permits both clinical and laboratory investigations without discomfort.

These characteristics of the evaporimeter are considered to be very useful in various fields to measure evaporation rate under natural conditions. The reproducibility and variability of the trans-epidermal water loss (TEWL) measurement by the evaporimeter had been investigated by Scott et al. (1982), Blichmann et al. (1987) and Pinnagoda et al. (1989) and the results were summarized and reported as guidelines for TEWL measurement by the standardization group of the European Society of Contact Dermatitis (Pinnagoda et al., 1990). In the clinical field, it has been already used for comparing the rate of evaporation from the burned skin with that from the normal skin, and the rate of evaporation from the dead skin with that from the normal skin. The values observed, however, showed still much deviation among the investigators.

The purpose of this study is to investigate the best technique for optimizing the accuracy of evaporation rate measurement by the evaporimeter prior to applying the evaporimeter to the field of clothing physiology, especially, to measuring the amount and the distribution of the evaporation rate over the human body surface in the wide range ambient temperature.

METHODS

The evaporimeter used was made by Servomed Co. (Sweden). It is designed to detect the difference of partial vapour pressure by a pair of humidity sensors and thermistors and the evaporation rate is calculated on the basis of this difference. Prior to the measurement, the sensor which is close to the skin (sensor A), was calibrated first under three standard humidity conditions: high, middle and low. The conditions were made by saturated salt solution, potassium sulphate (K_2SO_4 : 97 %) solution, magnesium nitrate ($Mg(NO_3)_2$: 53 %) solution, and lithium chloride ($LiCl$: 11 %) solution. Then another sensor (sensor B) was adjusted so that the evaporation rate duly became zero, which was done in relation to Sensor A indirectly.

The relative humidity, vapour pressure and evaporation rate were actually measured on the human body surface to determine the optimal time for recording after initial application of the probe to the skin and to confirm the comparability of the evaporimeter. The sites selected are the thigh, where wetted filter paper was mounted in one measurement and without wetted paper in another. During the measurement the probe was applied on each skin/wetted paper surface every 5 seconds for 10 minutes and detached from the skin for the following 10 minutes. The environmental conditions during the measurement was controlled at 28°C and 35 %R.H..

In order to investigate the effect of the fluctuation of environmental conditions, especially of the relative humidity on the evaporation rate, the successive measurements during a 20 minutes period were made in the controlled climatic chamber. Environmental conditions were set at air temperature 30°C, relative humidity 50 %, and air movement 0.2 m/s.

The accuracy of the evaporation rate obtained was confirmed by the following two steps.

In vitro: the relationship between the weight loss of the wetted filter papers and the evaporation rate on its surface was examined. The weight of the fully wetted filter papers with distilled water, which were filled up in the chalet (11.2 cm in diameter, 2.7 cm in depth) was measured by the electronic balance every 30 minutes for 2 hours under the three environmental conditions, that is, 21°C, 70 %, 28°C, 40 % and 33°C, 30 %, respectively. Simultaneously, the rate of evaporation on the paper surface was measured every 30 minutes for two hours by the evaporimeter.

In vivo: an average evaporation rate was calculated from 29 regional evaporation rates measured by the evaporimeter by weighing each skin surface area and it was compared with the total weight loss of the human subject. Evaporation rates were measured every 10 seconds for one minute at one site and at intervals of two minutes from one to the

next site under the condition of 25, 28, 31, 34 and 37°C of air temperature, respectively. Subjects consist of 10 female students aged between 22 and 34 years old. More exact information on this experiment will be mentioned in our next paper.

RESULTS AND DISCUSSION

Fig. 2 shows the charts obtained, in which the evaporation rate reached a stable constant state after 10 seconds from the start both for an increase and a decrease of the evaporation rate. On the thigh, the evaporation rate was about 10 g/m²h, and on the wetted filter paper placed on the thigh, the rate showed about 90 g/m²h. In both cases, after the probe was taken away from the measuring site, the observed value became close to zero within 10 seconds. This value did not completely return to zero in 10 minutes thereafter and continued to indicate the value between 1 g/m²h and 2 g/m²h. These values, however, are within the range of error as indicated in the guidelines by J. Pinnagoda et al. (1990). The time needed for recording after initial application of the evaporimeter probe to the skin was about 10 seconds in the charts. That was shorter than 30-45 seconds which was recommended as the time during which the probe should be applied to the skin by the guidelines. It may be long enough to measure an instant change of evaporation from the human body surface. Fig. 3 shows the results measured on the 29 different sites by one probe successively. Here, the values also became close to zero at the moment when the probe was detached from the measuring site. It was also confirmed that the optimal time for recording of the evaporimeter is very short and the regional evaporation rates on different sites can be measured by one probe successively.

Fig. 4 illustrates the change of the evaporation rate with the fluctuation of the relative humidity in a climatic chamber. The two factors are almost inversely proportional to each other. The evaporation rate becomes lower with an increase of relative

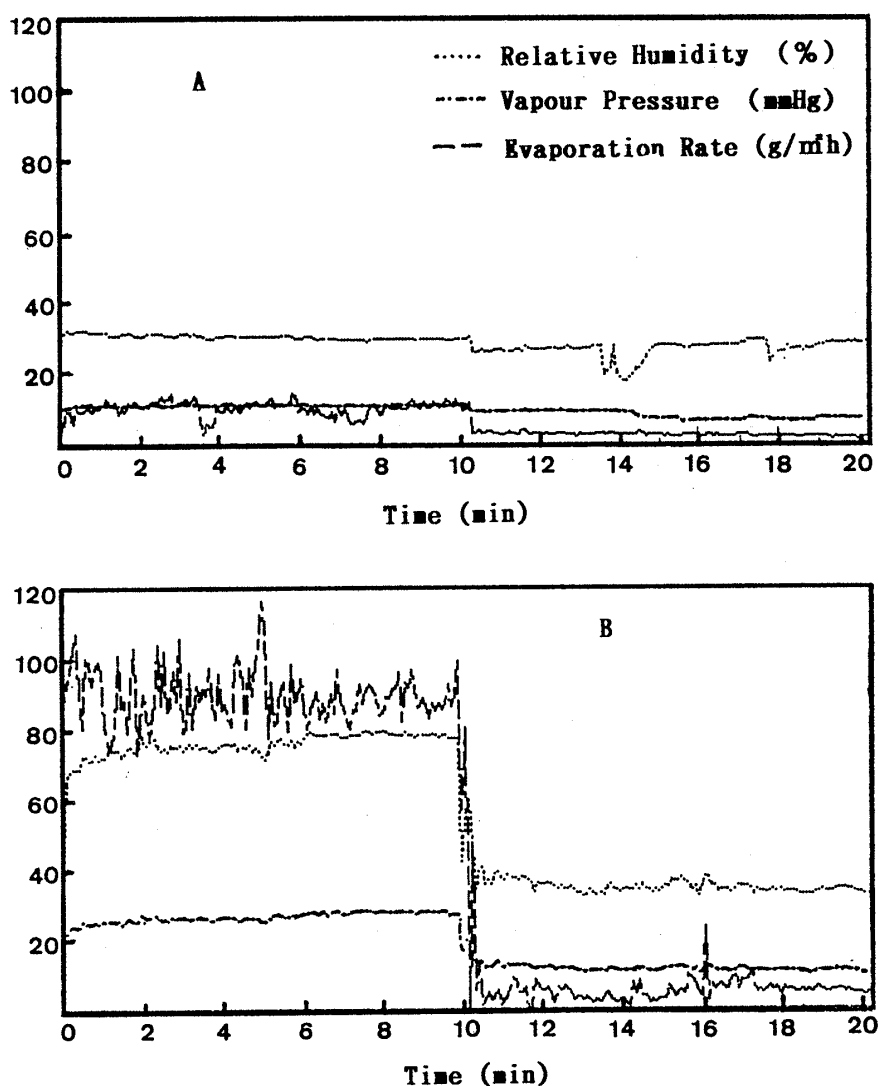


Fig. 2 Relative humidity, vapour pressure and evaporation rate measured for 10 minutes on the thigh(A) and on the wetted filter paper placed on the thigh(B), and for the subsequent 10 minutes off the skin.

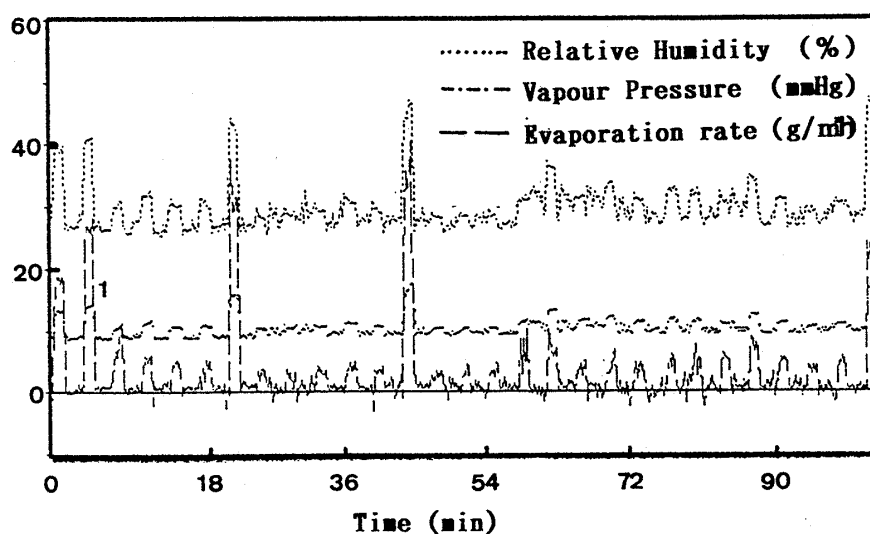


Fig. 3 An example of typical recording at the 29 sites of human body by one evaporimeter probe.

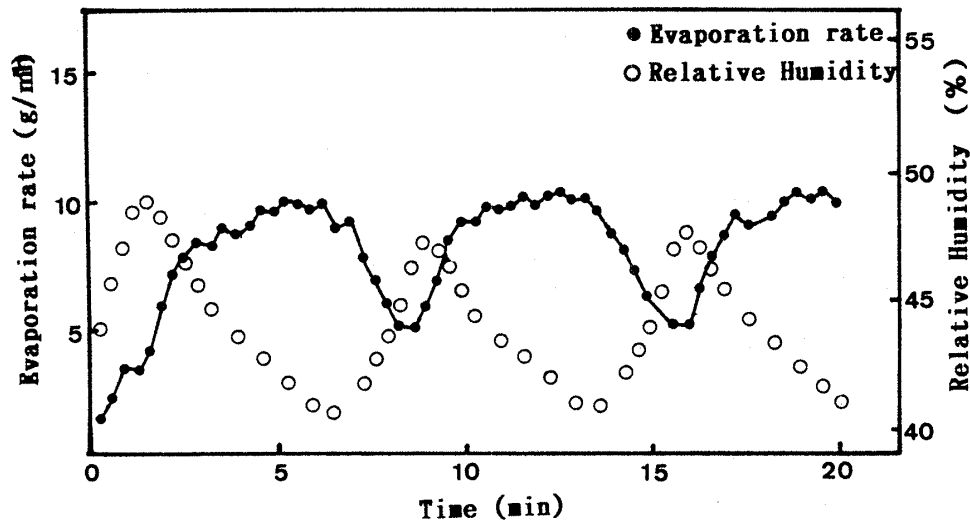


Fig. 4 The change of evaporation rate from the skin with the fluctuation of relative humidity in a climatic chamber.

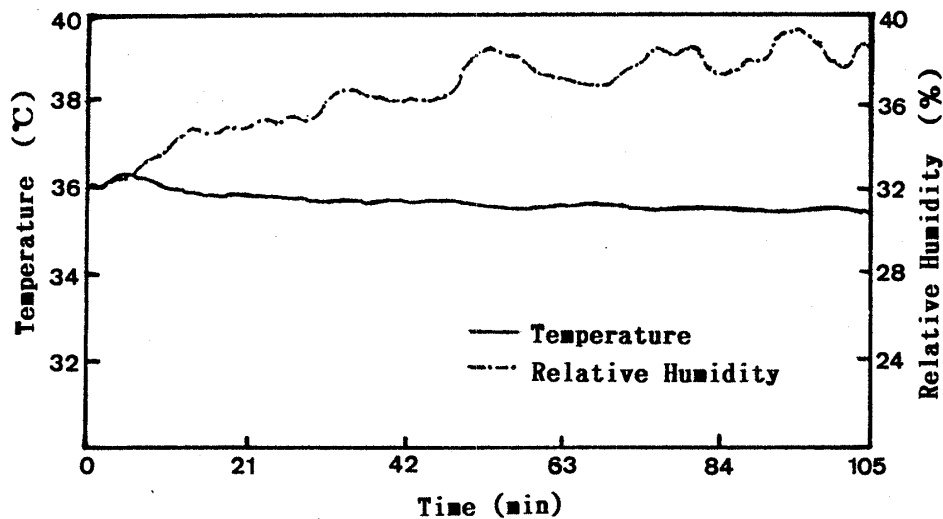


Fig. 5 The change of temperature and humidity in a climatic chamber after the control was suspended.

humidity and it becomes higher with a decrease of relative humidity. The guidelines recommended to use the climatic chamber for measurement of TEWL. The results, however, indicated the fluctuation of the relative humidity in the controlled climatic chamber definitely affected the evaporation rate. If the evaporation rate was measured with one probe moving from one site to another, it was difficult to determine how the observed values involve the effect of the fluctuation. In order to avoid the effect, the environmental conditions should be controlled until the time the experiment

began, and the control should be suspended to leave the conditions natural rather than be continued throughout the measuring period. Fig. 5 shows the change of temperature and humidity in the climatic chamber after the control was suspended at 36°C, 35 %R.H.. It was found that there was a slight decrease of temperature, approximately -0.5°C , and a slow increase of relative humidity about 5 %. Generally, in the range of the present experimental conditions, the temperature tends to be slightly decreased in the case of high ambient temperature and slightly increased in the case of low tempera-

ture, while the humidity tends to be slightly increased in high air temperature and slightly decreased in low air temperature.

Many investigators have studied the evaporation rate of the human subjects by different methods (Goodman et al., 1969; Kuno, 1956; Ohara et al., 1963; Lamke, 1970). Their observed values scattered over a wide range although they were measured at the same sites but with different apparatuses. In order to investigate whether our observed values are correct, the two calibration tests were conducted. As shown in Fig. 6, the correlation coefficient between the change in the weight of wetted filter papers and the rate of evaporation measured on the papers was 0.98, which was significantly high ($P < 0.01$). The regression formula between them is

$$Y = 2.77 + 2.59X \quad (1)$$

In Fig. 7, the total cutaneous evaporation rate measured by evaporimeter and calculated for each subject and for each ambient temperature was plotted against the whole body weight loss. The correlation coefficient was calculated to be 0.91, which

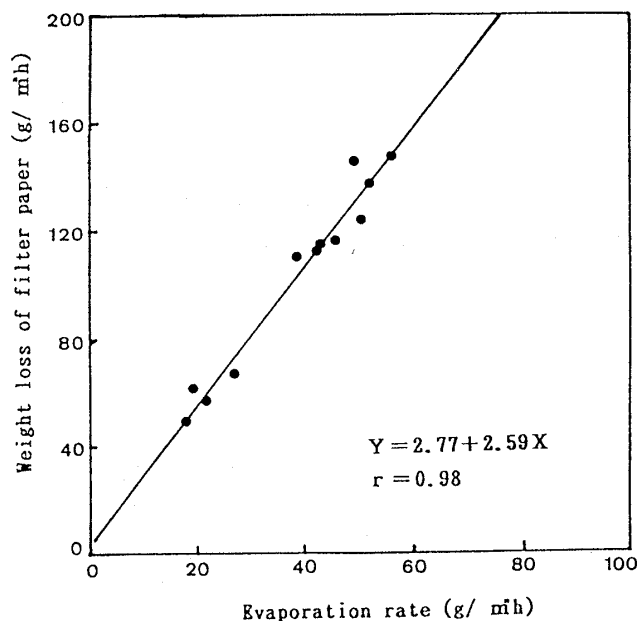


Fig. 6 Correlation between the water loss from the filter paper and the evaporation rate measured by evaporimeter.

was also significantly high ($P < 0.01$). The regression formula between them is

$$y = 2.06 + 2.53x \quad (2)$$

Skin wettedness(w) computed for reference from the corrected values by equation (2) was agreeable with the values reported by previous investigators; for example, w at insensible threshold was close to 0.06 (Mechael et al, 1977). From these results, it was

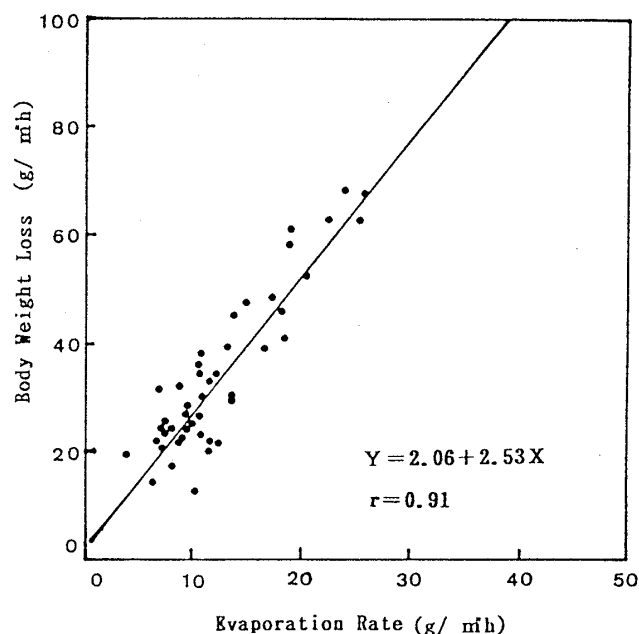


Fig. 7 Correlation between the body weight loss and the cutaneous evaporation rate measured by the evaporimeter.

clarified that the evaporation rate measured by the evaporimeter was lower than the real evaporation rate. In requesting accurate assessments, the value should be calibrated by a constant water evaporation device as recommended in the guidelines or as used in this study.

The evaporimeter is a useful device to measure the evaporation rate under natural conditions as mentioned earlier, and it has some advantages such as the response time becoming small, condition returning to zero point being quick and reproductive and relative sensitivity being good. However, in case the accurate values of evaporation rate are

required, careful attention must be paid to the change of the environmental conditions and calibration by a constant water evaporation device should be taken into consideration.

REFERENCES

- Blichmann, C. W. and Serup, J., 1987: Reproducibility and Variability of Transepidermal water loss measurement, *Acta Derm Venereol*(Stockh.), 67: 206-210.
- Goodman, A. B. and Wolf, A. V., 1969: Insensible water loss from human skin as a function of ambient vapor concentration, *J. Appl. Physiol.*, 26: 203-207.
- Herzman, A. B., 1957: Individual differences in regional sweating, *J. Appl. Physiol.*, 10: 242-248.
- Kuno, Y, 1956: Human perspiration, C, C Thomas publishers, Springfield: 370-376.
- Lamke, L-O., 1970: An instrument for estimating evaporation from small skin surfaces, *Scand. J. Plast. Reconstr. Surg.*, 4: 1-7.
- Mecheel, J. and Umbach, K-H., 1977: Thermophysiological properties of clothing systems, *Melliand Textilberichte*, January.
- Nilsson, G.E., 1977: On the measurement of evaporative water loss, Linköping studies in science and technology dissertations No. 11, and Linköping University medical dissertations No. 48.
- Nilsson, G. E., 1977: Measurement of water exchange through skin, *Med. Biol. Eng.* (Accepted for publication).
- Ohara, K. and Ono, T., 1963: Regional relationship of water vapor pressure of human body surface, *J. Appl. Physiol.*, 18: 1019-1022.
- Pinnagoda, J., Tupker, R. A., Agner, T. and Serup, J., 1990: Guidelines for transepidermal water loss (TEWL) measurement, 22: 164-178.
- Pinnagoda, J., Tupker, R. A., Coenraads, P. J. and Nater, J. P., 1989: Comparability and reproducibility of the results of water loss measurements: a study of 4 evaporimeters, *Contact Dermatitis*, 20: 241-246.
- Scott, R. C., Oliver, G. J. A., Dugard, P. H. and Singh, H. J., 1982: A comparison of techniques for the measurement of transepidermal water loss, 274: 57-64.

(Received March 10, 1992)

Teruko TAMURA Clothing Hygiene, Faculty of Home Economics, Bunka Women's University,
Yoyogi 3-22-1, Shibuya-ku, Tokyo 151, Japan

田 村 照 子 〒151 東京都渋谷区代々木3-22-1 文化女子大学 被服衛生学研究室