Outdoor Comfort Responses of Japanese Persons

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ABSTRACT: Most of the research on thermal comfort has dealt with indoor situations. Outdoors, people expect different climatic conditions and usually are dressed differently, according to the prevailing weather conditions. In particular, in contrast with indoor conditions, the inhabitants may be exposed to intense solar radiation and to winds, factors that modify greatly their response to the temperature and humidity conditions.

The experimental research described in this paper was conducted in Japan by Fujita Corporation. The objective was to study the effect of various design features on the comfort of Japanese persons dressed according to the seasonal climate.

The paper presents the methodology of the data analysis and the development of the formula on the basis of the experimental data, and the procedure for evaluating the residual effect of individual climate factors, and discusses probable reasons for the apparent negligible effect of humidity in a hot humid climate.

Conference Topics: 3 Comfort and well-being in urban spaces
Keywords: Comfort, Outdoor comfort, Japan

INTRODUCTION

Most of the research on thermal comfort has dealt with indoor situations. Outdoors, people expect different climatic conditions and usually are dressed differently, according to the prevailing weather conditions. In particular, in contrast with indoor conditions, the inhabitants may be exposed to intense solar radiation and to winds, factors which modify greatly their response to the temperature and humidity conditions.

Outdoor urban activities in the streets, plazas, playgrounds, urban parks, etc, may be greatly affected by the outdoor climatic conditions. Thus, for example, in a hot region on a hot summer day the thermal discomfort of people staying outdoors exposed to the sun may discourage them from utilizing the available urban parks, depending on the particular combination of the air temperature, the surface temperature of the surrounding areas, the wind speed and the humidity level. The availability of shaded outdoor areas may result in greater utilization of the open space by the public. In a similar way, in a cold region, a given combination of wind speed and air temperature, or the absence of the sun, may discourage people from staying outdoors while the provision of sunny areas protected from the prevailing winds may encourage public activities in that outdoor space.

In order to be able to evaluate the importance of affecting the outdoor climate in a particular direction by specific design details the designer should have some means for "predicting" the effect of a particular change in the climate on the comfort of the inhabitants. Most of the research on thermal comfort has dealt with indoor climatic conditions.

The experimental research described in this paper was conducted in Japan by Fujita Corporation, in 1994-1995 [1, 2]. Fujita is a company engaged in large scale design and construction of buildings and neighborhoods. The objective was to study the effect of various design features on the comfort of Japanese persons dressed according to the seasonal climate in the commercial plazas built by the company.

The research was conducted by means of a detailed questionnaire given to men and women under different experimental conditions for each one of the four seasons. The questionnaire had covered thermal sensations (hot/cold), thermal comfort (comfort/discomfort) and so on. The environmental variables were the ambient air temperature and humidity, the surface temperature of the surrounding areas and exposure to the sun under different wind speeds.
Analysis of the data enabled the development of a formula predicting the thermal sensation of subject staying outdoors as a function of air temperature, solar radiation and wind speed. The formula includes also the effect of acclimatization to seasonal changes in the climate. It was found that humidity and the surface temperature of the surrounding areas had negligible effect (Negligible effect of humidity was also found in comfort research in Thailand [4]).

1. THE EXPERIMENTAL PROCEDURE

Experiments were conducted under measured climatic conditions: air and surface temperatures, humidity, solar radiation and wind speed. A grassed open space and an asphalt parking area in a park in Yokohama City were chosen as the sites for the experiments.

Six subjects took place in each testing day. They were divided into three groups with different exposure conditions at very small distances between them. The first group was sitting under a large shade tree (SHADE), the second group was sitting in a nearby open area in the sun (SUN). The third group was also in the sun but behind a vertical wind break made of transparent polyethylene sheets supported on wood frames (WIND BREAK). The groups were rotated between the three exposure sites so that, on the average, every subject was exposed to the same conditions.

The experiments were carried out in the different seasons, from the summer of 1994 to the summer of 1995. In each season, experiments were conducted during two days, and in the summer for three days, for a total 9 experimental days. Each experimental day started at 9 a.m. and finished at 5 p.m.

The experiments consisted of questionnaire surveys on the subjects’ sensory responses and measurement of physical quantities. The measurements were carried out every hour in each exposure. Six subjects (males and females) ranging from those in their twenties to those in their fifties, have formed the test group. They worked in three pairs, each pair staying in one exposure for twenty minutes and moved to a different one. This procedure was repeated seven times a day. In each “test” the subjects were asked to sit still in their chairs for 15 minutes to get used to the condition, and filled in a questionnaire in the remaining 5 minutes.

The questionnaires dealt with thermal sensation and overall comfort. Thermal sensation is the perception of heat or cold, on a scale of 1 (very cold) to 7 (very hot). The scale of the overall thermal comfort level is from 1 (very uncomfortable) to 7 (very comfortable), when a level 4 is neutral, when one does not feel any thermal discomfort, to correspond with level 4 of the thermal sensation. The comfort levels above 5 were included so that effects which produce “pleasure” beyond just comfort, such as the wind in the hot humid summer and the sun in the winter could be identified (see discussion below).

2. SUBJECTS’ THERMAL RESPONSES

Figure 1 shows the thermal responses of the subject, under the three different exposure conditions, at the different seasons, as a function of the ambient air temperature. Clear separation can be seen between the three exposure conditions. As expected, the highest thermal sensations were of the persons exposed to the sun with a suppressed wind speed and the lowest responses were for the persons under the shade of a tree. The objective of the formula development was to quantify these effects.

3. THE PREDICTIVE FORMULA

Initial check of the data has shown strong effects of the ambient air temperature, $T_a$, the solar radiation, $SR$, and the wind speed, $WS$, on the thermal sensation, $TS$. No clear effects on the thermal sensation, of the humidity and of the temperatures of the surrounding surfaces, were evident. Another interesting observation was an apparent seasonal adaptation: in winter the thermal sensation at a given (high) temperature was higher than the response to a similar (low) temperature in summer. This change in the response was caused by the different clothing in the different seasons, but may also represent, in part, seasonal physiological adaptation. In each season the average air temperature of the experimental days was calculated as $GT_a$.

Consequently, an initial formula was developed on the basis of the three significant climatic factors: air temperature, $T_a$, solar radiation, $SR$, and wind speed, $WS$. The resulting formula is,
T.S. = (1.83 - 0.05*GTa) + (0.135*Ta) + (0.00195*SR - 0.6) - (0.4915*Ln(WS)).

The first component of the formula represents the seasonal adaptation, including change of common clothing, as a function of the season's average temperature, GTa, as mentioned before.

The Correlation Coefficient between the measured and the computed thermal sensation is 0.9191.

Figure 2 shows the measured and the computed thermal sensations at the different exposures. There is no separation between the three exposure conditions.

3. SOLAR RADIATION EFFECT

Outdoors, exposure to solar radiation is a major factor affecting comfort. Thermal sensation votes express this effect in subjective terms. However, it is possible to express the average effect of solar exposure in terms of the equivalent change in the ambient air temperature.

Figure 3 shows the average thermal sensations expressed as a function of the ambient air temperature, DBT, for the three exposure groups: in the shade of a tree, exposed to the sun and exposed to the sun behind a wind brake.

From the regression lines it can be seen that at 20 °C the average vote of the subjects in the SHADE was 3.1, in the SUN it was 3.9 and under WIND BRAKE was about 4.4. The subjects under SHADE had voted the same sensations at 27.5 and 32.5 °C, respectively. Thus, the average effect of exposure to the sun with the unobstructed wind speed was equivalent to an elevation in air temperature of 7.5 °K. The effect of the reduced wind speed, under sun exposure, was equivalent to an elevation of 5 °K.

It is of interest to note that in research in Israel on outdoor comfort [3] it was also found that, in comparing the thermal sensations of subjects the in the shade and exposed to the sun, the difference in the votes was equivalent to about 7 °K.

4. RESIDUAL EFFECT OF ADDITIONAL FACTORS

Once a formula, based on a number of independent variables, is formulated, the effect of additional factors can be evaluated by expressing the difference between the measured and the computed responses as a function of the factor of interest.

4.1 The Residual Effect of Humidity.

In the experiments relative humidity was measured, and for the analysis it has been converted into Absolute Humidity, HR, (gr/Kg).

In order to quantify the residual effect of the HR, the differences between the observed and the computed thermal sensations, for all test conditions except the winter experiments, were expressed as function of the HR in each test, as can be seen in figure 4.

The residual effect of the humidity (0.02*HR – 0.2) was rather small and statistically may be insignificant. However, it can be added to the predictive formula to increase slightly its correlation coefficient.

4.2. Residual Effect of Surface Temperatures.

The tests were conducted both over grass and over asphalt areas, so the "sunny" subjects were exposed
to very different ground temperatures. Thus it was possible to check the quantitative effect of the elevation of the surface temperatures above the ambient air temperature, DeltaT, which was up to about 25 °K.

The difference between the measured and the computed thermal sensations were expressed as a function of the difference between the surface temperature and the ambient air temperature, as is shown in figure 5.

\[ y = 0.0155x - 0.0587 \]
\[ R^2 = 0.0419 \]

Figure 5: Residual effect of the surrounding's surface temperature.

The residual effect of the "radiant temperature" (0.0155*DeltaT-0.06) is small and statistically may be insignificant. Still it can also be added to the formula to increase slightly its correlation coefficient.

When these two factors are added to the predictive formula the correlation coefficient is "increased" from 0.9191 to 0.9244. In practice it seems that there is no point in increasing the complexity of the formula for such minute gain in the prediction accuracy.

5. DISCUSSION

The very small effect of the humidity found in this research was not expected and it is not in agreements with findings in studies conducted in climatic chambers in the USA and in Europe. It is of interest to note that in an indoor comfort research conducted in the hot humid climate of Bangkok [4] it was also found that the effect of humidity was very small.

One may speculate that people living in and acclimatized to a hot humid climate may be more accustomed to the high humidity than people living in mostly air conditioned houses in the USA and people living in Europe. It is worthwhile to check this possibility in additional studies of comfort in hot humid places.

As to the apparent very small residual effect of the surface temperatures, it should be noted that the subjects were exposed to solar radiation and to the high surface temperatures at the same time, although there were significant differences in the surface temperatures of the grass and the hard surfaces. Additional studies on outdoor comfort, focusing on the effect of surface temperatures, may clarify this issue.

6. DESIGN IMPLICATIONS

The finding that the effect of exposure to the sun, for subjects with unobstructed wind, was equivalent to an elevation in air temperature of 7.5 °C, and the similar finding in the research in Israel, provide quantitative data to illustrate the importance of providing shade in regions with hot summers. Shade in outdoor spaces can be provided either by trees or by built architectural elements. Planners and architects should take this factor into account in designing outdoor spaces in any region with hot summers, either hot dry or hot humid.

The finding that the effect of reducing wind speed by about 50% under sun exposure, by blocking the wind, was equivalent to an elevation of about 5 °C in the air temperature, demonstrates the importance of preventing blockage of the wind, especially in hot humid regions. Such blockage can be created inadvertently by landscape elements such as high shrubs, low trees, etc. Urban designers in hot humid regions should take also this factor into account in designing green areas. In particular, high shrubs, above 70 cm. high, and trees with low canopy, can greatly reduce the wind speed.

REFERENCES


