Evaluation of ultraviolet radiation protection of a membrane structure using a UV Shade Chart

Toshimasa Kawanishi
Nihon University, Funabashi, Chiba, Japan

ABSTRACT: This paper reports a study which calculated shade effect against UV radiation using a UV Shade Chart. Ultraviolet radiation damages the skin. The use of sun-shading is an effective means of blocking this radiation. Membrane structures are sometimes used as sun-shades – however, it is difficult for a membrane structure to be evaluated for a shade effect against ultraviolet radiation because of its free shape. The UV Shade Chart which has been developed expresses sky erythema radiance as point density. The Chart has been used to evaluate several kinds of shades by calculating the architectural sun protection factor (ASPF).

Keywords: UV, shade, evaluation, protection

INTRODUCTION

Membrane structures (as shown in Fig.1) have become popular owing to the development of materials and design techniques and they are also used as sunshades. For the purpose of evaluating the protection performance of these facilities as a sunshade, it is necessary to examine two physical quantities, the amount of solar radiation and ultraviolet radiation. Solar radiation can be examined using a sun shadow diagram. However, there is no established method to estimate the amount of ultraviolet radiation coming into a structure, because ultraviolet radiation is invisible, greatly scattered and comes from the sky as well.

This research targeted ultraviolet radiation through clear sky, as both sky factors and daylight factors cannot be used in estimating the irradiation as in the case of visible rays. The author proposed a UV shade chart and an architectural sun protection factor ASPF for the purpose of examining erythema inducing ultraviolet radiation under the sunshade (Author 2007). Erythema inducing ultraviolet radiation is the total of the values measured by spectral radiance measurement of ultraviolet radiation multiplied by the reference erythema action spectrum by each frequency defined by the International Commission on Illumination; CIE. ASPF can be obtained by the UVINDEX outside of the sunshade divided by the UVINDEX measured under the sunshade. ASPF shows how many times it can delay the occurrence of erythema in comparison with the case where there is no shade.

Simple-shaped sunshades like beach parasols have been introduced. However, this paper is the first that has presented the sunshade with a complex shape like a membrane structure. Erythema inducing ultraviolet radiations inside and outside of a structure was measured, and ASPF was obtained from these actual measured values. Furthermore, they were compared with the ASPF obtained from the UV shade chart and the correlation between them was obtained.

Fig.1 Membrane Structure

There is a literature titled “Under Shade” concerning ultraviolet radiation and sunshade produced and distributed by the Cancer Council of South Australia (Cancer Council 2003), and there are those titled, “Shade for Young Children”, “Shade for Sports Field”, “Shade for Public Pools” (Queensland Health 1995,1996,1997) and “Creating Shade at Public Facilities” (Australian Institute of Environmental Health 1998). They can be applied in Japan in their entirety except some minor points as incidence of skin cancer, southern hemisphere or northern hemisphere, kinds of shade trees, etc. In the literature, ultraviolet radiation is classified into direct ultraviolet radiation and indirect ultraviolet radiation. Indirect ultraviolet radiation includes sky ultraviolet radiation caused by scattering in the sky. Sky ultraviolet...
radiation reaches 50% of total sky ultraviolet radiation at sun altitude angle 70 degrees. Therefore, only blocking direct sunshine is not enough for protection against ultraviolet radiation, and it is important to know the amount of sky ultraviolet radiation and the incoming radiation amount through a sunshade structure. However, there is no description of how to evaluate the ultraviolet radiation under a sunshade.

There are researches on sunshade and ultraviolet radiation including “Shading from Ultraviolet Radiation” (Tonder 1999) and “Ultraviolet Radiation under Beach Parasol” (Author 2002). Regarding membrane structure and ultraviolet radiation, in particular, there are researches of ultraviolet daylight factor (Author 1998). There are existing researches on radiance distribution of ultraviolet radiation on clear sky (Grant 1997, Sasaki 1999, Author 2001, Seckmeyer 2006), “Sky Radiation Distribution of Erythema Inducing Ultraviolet Radiation” (Author 2006.2008). These researches, except a few exceptions, are not intended for erythema inducing ultraviolet radiation or are limited to the simple shape of shade like a beach parasol. This research is for the structure with a complex shape like a membrane structure and also for the verification and performance evaluation of the UV shade chart produced with erythema inducing UV radiation taken into consideration.

1. UV SHADE CHART

UV shade chart is a chart produced for the purpose of evaluating the defence performance of sunshades against ultraviolet radiation. The spectral radiation intensities at 145 points in the sky at northern latitude of 35 degrees and sun altitude angles of 60 and 70 degrees were measured when the sky was clear and then they were weighted with CIE erythema action spectrum (CIE 1993). In this way, the erythema inducing ultraviolet radiation was calculated as shown in Fig.2, and the intensities of the radiation were expressed by the dots of space density. The measuring equipment, measuring results, calibration and chart creation were described in the details of the paper that was already presented (Author 2009). Fig. 3 shows the UV shade chart of the sun altitude angle of 70 degrees. The centre of the circle is equivalent to the zenith and the circumference to the horizon. The figures on the circumference are horizontal angles in a clockwise direction, sun azimuth angle being considered as “0”. The total number of dots is 100. There is an area near the sun azimuth angle where the density of dots is high. The number of dots in this area is approximately 50% of the total and the other 50% is in the other sky area. This shows how greatly the erythema inducing ultraviolet radiation scatters in the sky.

How to use the UV shade chart is as follows: 1) Take photographs with a fish-eye lens upwardly from a measuring point under an existing sunshade, print them and make projections. 2) Superpose the projections and the UV shade chart so that both azimuth directions are at the same position. 3) Divide the total points, Pt, by the points, Ps, of the part of sky, and calculate the ASPF.

$$\text{ASPF} = \frac{P_t}{P_s}$$ (1)

ASPF shows how many times it can delay the occurrence of erythema in comparison with the case where there is no shade, just as the case of the sunscreen SPF. If its ASPF level is at 3-5, the sunshade can be used for lunch and tea times. If 6-9, it can be used for sports spectator for two hours, and if more than 10, it is appropriate for outdoor work.

Fig.2 Sky erythema radiance at sun altitude 70°

Fig.3 UV shade chart

The UV shade chart was prepared based upon the conditions of the sun altitude angle of 70 degrees, a clear sky and the measured figure of cloudiness of 0-1, so it cannot be applied to the case at other sun altitude angles and when the cloudiness is 2 or more. This was used because it is important to make the design of sunshades presuming the conditions where the most severe ultraviolet radiation may harm the skin. Because the sun is moving, when people stay under the sunshade for a long time, it is possible to extrapolate ASPF by superposing the UV shade charts of each sun latitude angle by adjusting them to the azimuth directions at that time. The UVINDEX is to express the amount of erythema inducing ultraviolet radiation, so the sunburn time can be estimated from its amount. This research is to estimate the occurrence of the sunburn, that is to say erythema, under a sunshade, so the UVINDEX was used.
2. ESTIMATION OF ASPF OF SUNSHADE

2.1. Outline of measurement
The UVINDEX of the membrane structure of the Department of Science & Technology, Nihon University, Funabashi Campus, was measured and a fish-eye photographs were taken in July and August, 2007, in the condition of 70 degrees of sun altitude angle and a clear sky. A UV sensor 7843, a product of DAVIS, was used for the measurement of the UVINDEX as shown in Fig. 2. Its measurement wavelength was 250-400 nm and has the sensitivity of reference erythema action spectrum that CIE has adopted. The measuring point was 0 m above the ground or on a chair. The total sky UVINDEX during the measurement period was 7-10. The UV transmission rate of the membrane material was extremely low, and it was confirmed by a UVINDEX meter that there was not UV radiation transmitted through the membrane.

2.2. Measurement results
The center height of the membrane structure was 4.7 m, the outer height was 2.5 m and both the width and depth were 8 m. Fig. 3 shows a panoramic photo of the structure. It is hybrid architecture of a single layer lattice shell of a two-way grid with a string material arranged inside a curved surface. This structure makes it possible to minimize the sizes of materials and reduce the cost. It also has the characteristics to improve the resistance to wind and buckling stability. The membrane material is a teflon coated glass fiber woven textile. Forty-nine measuring points were established on earth in the sunshade.

The range of ASPF level of 3-5 is broad, so this level of ASPF is useful for sun shading within approximately one hour. Photographs were taken by a fish-eye lens and they were superposed with the chart, the number of dots in the part of sky was counted, an ASPF was calculated, and the relationship between this ASPF and that obtained from actual measured values was examined. Fig. 4 shows a fish-eye photograph. Fig. 5 shows the values of ASPF actually measured at a sun altitude angle of 70 degrees. The bold line shows the range of the sunshade and the dotted line shows the range of the shadow of the sunshade caused by direct sunlight. The highest value of ASPF was approximately 8. The ultraviolet radiation does not reach the central part of the sunshade so much. The range of more than ASPF6, which delays sunburn time by approximately two hours, was spread more broadly, so this structure is useful as a sunshade.

Fig. 6 shows an ASPF distribution chart calculated from a fish-eye photograph and UV chart. It agrees well with the ASPF distribution chart obtained by the actual measurements. An ASPF of 5-6 were observed in neighborhood of the center of the sunshade. A larger level of ASPF was observed in the center, and the smaller level of around 1 was observed at the boundary between the edge of the sunshade and sky. Fig. 7 shows the comparison of ASPF obtained from a fish-eye photograph and UV shade chart and that by the actual measured values.
3. CAPACITY

The capacity of the structure was calculated based upon the conditions before and after the culmination altitude of the sun under a clear sky in the summer and during staying time of an hour. It is about one hour between the sun altitude angle of 70 degrees in AM and that in PM. Each clock time of the sun azimuth angle of the sun altitude can be known from a sun position diagram. Interpose the two UV shade charts displacing azimuth direction, compare the ASPF in each position of the two charts and keep a lower ASPF. Fig. 8 is a diagram written in this way. Presuming that a human body dimension in a sitting position is $1 \times 1$ m, if the area of the range of ASPF 3, 36 m$^2$, is divided by it, the quotient is 36, and it is the capacity. In this way, if the time zone and staying time are determined, the capacity can be estimated. However, because humans rarely can sit down in the same place and in a fixed posture for one hour, the actual capacity will be less than that.
CONCLUSION

This research can be summarized as follows:

1. Architectural sun protecting factor, ASPF, of a membrane structure was calculated and presumed by the actual measurement of its ultraviolet radiation protection performance and using a UV shade chart.
2. The ASPF in the neighborhood of the center of a membrane structure of 2.5 m in height and 8 m in width and depth becomes 5-8, and ultraviolet radiation can be protected against for long time. As the result of calculation of capacity presuming that the staying time is one hour, the capacity in the range of ASPF 3 was 36.

The important points in using UV shade chart are as follows:

1. Use it under the conditions of summer, culmination altitude of the sun, clear sky and cloudiness of 0-1.
2. Pay attention to the azimuth direction and horizontal line when taking photographs.
3. It is desirable to use it where there are no buildings, no trees and no ground reflection in the area.

REFERENCES

CIE (1993). Reference Action Spectra for Ultraviolet Induced Erythema and Pigmentation of Different Human Skin
Types, CIE RESEARCH NOTE, CIE Technical Collection 103/3
International Commission on Illumination (1993). Reference Action Spectra for Ultraviolet Induced Erythema and
Pigmentation of Different Human Skin Types, CIE Publication 103/3 USA
Active Radiation, J. Of Applied Meteorology, Vol.36, pp.1336-1345
Cancer Council, South Australia
Eng., AIJ, 555, pp.347-352 (Japan)
Environ. Eng., AIJ, 587, pp.87-91 (Japan)
Environ. Eng., AIJ, 623, pp.131-137 (Japan)
Australian and New Zealand Architectural Science Association
Seckmeyer G. & Wuttke S. (2006). Spectral radiance and Sky luminance in Antarctica: a case study, Theoretical and
Applied Climatology, 2006
Radiation for Shading Structure, CIE,3c-, pp9,230
Queensland Health (1996) Shade for Public Pools
Queensland Health (1997) Shade for Young Children