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Increasing the Ultraviolet Protection Provided by Shade Structures

D.J. Turnbull*, A.V. Parisi
Centre for Astronomy, Solar Radiation and Climate, University of Southern Queensland, Toowoomba, 4350, Australia.

*Corresponding author. Tel.: +61-7-4631-1488; fax: +61-7-4631-1530
E-mail address: turnbull@usq.edu.au

Abstract

The side openings of a shade structure have a direct influence on where the shade is located and the level of scattered UV in the shaded area. UV exposures were assessed for the decrease in scattered UV beneath specific shade structures by the use of two types of side-on protection, namely, polycarbonate sheeting and evergreen vegetation. Dosimetric measurements conducted in the shade of a scale model shade structure during summer and winter showed significant decreases in exposure of up to 65% for summer and 57% for winter when comparing the use and non-use of polycarbonate sheeting. Measurements conducted in the shade of four shade structures with various amounts of vegetation covering different sides, showed that adequate amounts of and positioning of vegetation decreased the scattered UV in the shade by up to 87% for the larger solar zenith angles (SZA) of approximately 67^o and up to 30% for the smaller SZA of approximately 11^o when compared to the shade structure that had no surrounding vegetation.

Keywords: Scattered UV; shade structures; protection

1. Introduction

Utilising shade as a means to decrease personal exposure to direct solar UV radiation is a simple and generally effective practice. However, it is not advisable to use shade as the sole UV minimization strategy. This is because there can be a considerable amount of scattered UV prevalent in the shade. Scattered UV radiation is present within the shade because it is scattered by the atmosphere and surroundings, and enters through the side openings of the shade structure. The size of the structure and the area of the side openings have a direct influence on the level of scattered UV in the shaded area. Also, at certain times of the day, the shade may not necessarily always be beneath the shade structure [1]. At higher solar zenith angles (SZA), it may be outside the shade structure. Therefore, personal UV exposure is dependant on the position of the occupant within the shade (for example, where they are sitting) and the duration of exposure [2]. The proportion of scattered UV under shade structures increases as the solar zenith angle increases [3].

While many people associate shading with the perception of a decrease in temperature, temperature is not indicative of UV levels and scattered UV can still reach the shaded skin and eyes [4,5]. People will generally seek shade in summer because it is hot, but in winter people will seek places that are warm. Given choice, students appear to prefer light and/or warm shade that is large enough to group within [6]. If a shaded space is not comfortable, it will not be used; on the other hand, comfortable shaded spaces will be used by people seeking relief from heat, not UV [7]. The best shade structures are visually appealing as well as providing effective shade [6]. Another challenge is to reduce the risks of UV exposure without sacrificing the benefits of outdoor activity [4]. It is of particular importance that shade is provided where the outdoor activities of infants and children are likely to occur [5].

Past research (for example, [1,3]) has shown that scattered UV levels under shade structures are sufficiently high enough to cause sun related damage. To the authors' knowledge, no previous research has quantitatively measured what effects side-on protection would have in reducing scattered UV beneath shade structures. Resources that can be used to reduce scattered UV in the shade consists of, shade cloth, polycarbonate sheeting and various types of vegetation. Polycarbonate sheeting is useful because it is manufactured in various clear or tinted colours. Therefore, the transparent polycarbonate sheeting could be used on some sides of a shade structure to reduce UV but still allow visible light to enter beneath the shade structure. To the authors' knowledge, no previous field based research has been conducted on the effects of side-on protection on reducing scattered UV beneath shade structures. This research shows how scattered UV levels in the shade are influenced by side-on protection for a range of solar zenith angles.

2. Materials and Methods

2.1. Model shade structure

The physical dimensions of a common public shade structure described in previous research [1] were used to build a half-size scale model (refer to Figure 1) at the University of Southern Queensland, Toowoomba, Australia. The model was constructed so it would be possible to conduct UV exposure measurements using manikin head forms in the shade and also to structurally modify the shade structure. The results from this model are applicable to the full size shade structure. Broadband erythemal UV and UVA measurements were conducted beneath the full-size shade structure and also beneath the scale model to validate the scale model. Differences between the UV and UVA irradiances for the model and full-size shade structures were found to be less than 4%. Details of the scale model shade structure are as follows:

- The scale model is of hexagonal shape with sides measuring approximately 1.10 m wide, 1.05 m high at the eaves, and approximately 1.50 m high at the apex. The overhang of the roof is roughly 0.28 m, making the roof area approximately 4.80 m^2 (Figure 1).

2.2. Anatomical facial dosimetry

Polysulphone dosimeters that have a response to UV radiation approximating the human skin erythemal response [8] were employed in this research to measure the erythemal UV exposure to specific anatomical facial sites. Polysulphone dosimeters were placed at sixteen different facial sites, as shown in Figure 2, on a manikin head form. These facial sites have been employed based on similar sites selected in previous research to quantify the erythemal UV facial exposures [9]. For each set of measurements, two head forms with polysulphone dosimeters attached, and affixed to rotating bases (rotating at approximately 2 revolutions per minute) were used. The height of the headforms above the ground was approximately 0.85 m. One headform was positioned in the centre of the model shade structure and one headform was positioned at least five metres from the shade structure in the full sun. The manikin head forms were then exposed from 9:00 a.m. to 12:00 noon at a sub-tropical Southern Hemisphere site (lat 27.5°S, long 151.9°E; 692 m above sea level). A series of measurements were conducted in winter and summer to account for the variation in exposure levels, SZA and atmospheric conditions experienced in the different seasons.

For each dosimeter, the absorbances were measured at four different sites over the dosimeter in order to minimise any errors due to any possible minor variations in the polysulphone film over the size of the dosimeter [10]. The polysulphone dosimeters were calibrated with a UV spectroradiometer (Bentham Instruments, Ltd, Reading, UK) using an approach similar to Parisi and Kimlin [11].

The spectroradiometer is based on a double grating monochromator, a UV sensitive detector and amplifier with software variable gain provided by a programmable high voltage power supply [12]. The interior of the spectroradiometer enclosure is temperature stabilised to 23.0 ± 0.5°C, using a Peltier heater/cooler unit. The input optics of the spectroradiometer are provided by a PTFE (polytetrafluoro ethylene) diffuser [13] and connected by an optical fibre to the input slit of the monochromator. The spectroradiometer is programmed to start scanning at dawn, and thereafter every 5 minutes till dusk.

For the calibration, the dosimeters were subjected to a series of solar UV exposures on a horizontal plane next to the input optics of the spectroradiometer while measuring the solar UV spectrum. The erythemal UV irradiances, UV_{ery} were calculated with Equation (1) for each five minute spectral scan and Simpson's rule employed to calculate the erythemal UV exposures. The erythemal irradiances were calculated as follows:

$$UV_{ery} = \int_{UV} S(\lambda)A(\lambda)\Delta\lambda \qquad (1)$$

where S(λ) is the spectral irradiance measured with the spectroradiometer, A(λ) is the erythemal action spectrum [14] and Δλ is the wavelength increment of the measured spectral irradiance, in this case 0.5 nm, and the summation is over the solar terrestrial UV waveband of approximately 295 nm to 400 nm. These exposures were related to the change in absorbance to provide a calibration curve for the dosimeters for summer and winter as seen in Figure 3. The exposure shade ratios, UV_{ESR} shown in Table 1 were calculated according to the following equation:

$$UV_{ESR} = \frac{UV_S}{UV_H} \times 100\% \qquad (2)$$

where UV_S is the erythemal UV in the shade for a specific anatomical facial site and UV_H is the full sun erythemal UV measured on a horizontal plane.

2.3. Polycarbonate Sheeting

Three types of polycarbonate (PC) sheeting were considered for this research, based on the ability to significantly decrease UV transmission but also to transmit as much visible and infrared radiation as possible.

This is because near infrared radiation heats both the air it passes through and solid objects that it is incident on. The transmission of the visible waveband is important in order to provide a structure that is not too dark and does not give the impression of being enclosed. The style of polycarbonate sheeting used was Laserlite 2000 with a Roma profile (corrugation depth of approximately 0.018 m) and colours of clear, grey tint and bronze tint (supplier, Laserlite Australia). For the series of measurements with the manikin head forms, the polycarbonate sheeting was attached to the north and north-east facing sides of the model shade structure. This was done for the higher SZA in the morning, as the shade is generally situated away to the south/south-west of the shade structure as can be seen in [1]. Attaching the polycarbonate sheeting to these sides then brings the shade back under the shade structure and reduces scattered UV entering from the northern and north-eastern directions.

2.4. Spectral properties of polycarbonate sheeting

The transmittance characteristics of the various types of polycarbonate sheeting used were tested with a spectrophotometer (model UV1601, Shimadzu Co., Kyoto, Japan) and are shown in Figure 4. Maximum transmission values were observed in the near infrared region with 89%, 64% and 49% for the clear, bronze tint and grey tint, respectively. Negligible transmission was observed below 365 nm for the three types of polycarbonate sheeting. Despite most of the polycarbonates being virtually transparent in the near infrared and visible, all samples had zero UVB transmittance and very low UVA transmittance below 365 nm. The low ultraviolet values indicate that polymeric materials provide substantial protection against solar direct UV [2].

2.5. Vegetation

Public shade structures of similar dimensions with varying degrees of evergreen vegetation surrounding them were employed in this research and were situated at public sporting fields located in the city of Toowoomba (27.5°S, 151.9°E, 692 m above sea level), Australia. The majority of the surrounding vegetation was made up of *Melaleuca linariifolia* and *Melaleuca quinquenervia*, varying in height from 2 to 4 m. This vegetation is effective at shading due to the density of the leaves and the height and width that it grows to. The shade structures used for the research on the effects of vegetation are based on the small shade structure used in previous research by Turnbull and Parisi [3]. The small shade structures are 2.55 m wide at the sides, 2.28 m high at the eaves and approximately 3.10 m high at the apexes. The overhang of the roofs is approximately 0.69 m, making the roof area of the small shade structures 15.5 m^2.

Four shade structures were used for this specific research into the effects of surrounding vegetation. One shade structure had no surrounding vegetation and was used as a control (□). The other three structures had varying amounts of vegetation covering different sides of the shade structures. Shade structure (Δ) had varying amounts of vegetation on the north-western, western and south-western sides. Shade structure (O) had vegetation to the north-eastern, northern, north-western and western directions. These two shade structures were located on the north-western corner of a sports field. The fourth shade structure (∗) was located at the south-western edge of a sports field, with vegetation to the southern, south-western and western directions. The UV irradiances were measured with a hand held Robertson-Berger (RB) meter (model 3D V2.0, Solar Light Co., Philadelphia, PA, USA) [15] fitted with a UVA detector and an erythemal weighted UV detector, between 9:00 am and 12:00 noon. The RB meter was calibrated with the UV spectroradiometer described above, for a range of SZA from 15^{o} to 60^{o}.

3. Results and Discussion

3.1. Anatomical facial exposures

The anatomical facial exposure shade ratios for summer and winter are shown in Table 1 for the cases of no PC and each type of PC. The majority of measurements conducted in summer showed a significant decrease in exposure ratios when PC sheeting was used. Exposure ratios to the eyes, bridge of nose, forehead, cheeks and back of the head in the shade with the use of PC sheeting were up to 65% less than the exposures in the shade with no PC sheeting during summer. This decrease can be credited to the positioning of the polycarbonate sheeting, thereby bringing the shade back under the shade structures roof and reducing the large amount of scattered UV entering from the northern and north-eastern directions.

The polycarbonate sheeting had slightly less of an effect on erythemal UV exposures during winter, with exposure ratios of up to 57% less than compared to no PC sheeting. This reduction in difference between the use and non-use of polycarbonate sheeting maybe attributed to the increase in diffuse UV for the larger SZA seen during winter. However, in some cases, the facial exposure shade ratios with the polycarbonate sheeting in place were almost as high as those without the sheeting (for example, the cheeks). Broadband diffuse erythemal UV (UV-Biometer Model 501 Version 3, Solar Light Co.) [16] measurements showed elevated levels of diffuse erythemal UV for the days when the bronze tint and grey tint polycarbonate sheeting was being used that would account for these instances.

Measurements conducted in the shade of a scale model shade structure during summer and winter showed that the addition of any type of polycarbonate sheeting to the northern and north-eastern sides of the scale model shade structure had a direct influence on decreasing the UV exposure levels in the centre of the shade structure.

3.2. Surrounding vegetation

As can be seen in Figure 5 and Table 2, the control shade structure (□) received the highest levels of UV in the shade as expected, with a maximum of 0.14 MED/10 min and a minimum of 0.09 MED/10 min. Shade structure (Δ) had varying amounts of vegetation on the north-western, western and south-western sides. This shade structure received slightly lower levels of UV in the shade with maximum and minimum exposures of 0.10 MED/10 min and 0.03 MED/10 min, respectively. Shade structure (O) had vegetation to the north-eastern, northern, north-western and western directions. This particular arrangement of vegetation produced the lowest levels of UV in the shade, with a maximum of 0.08 MED/10 min and a minimum of 0.01 MED/10 min. These two shade structures were located on the north-western corner of a sports field. The fourth shade structure, (∗), was located at the south-western edge of a sports field, with vegetation to the southern, south-western and western directions. This shade structure received maximum and minimum erythemal UV levels of 0.11 MED/10 min and 0.03 MED/10 min, respectively.

As can be seen in Figure 5a and 5b, the difference in the UV levels beneath the three shade structures with surrounding vegetation compared to the UV levels beneath the shade structures with no vegetation increased as the SZA increased from approximately 30^o to 70^o. At the low SZA of approximately 10^o to 20^o little difference between the respective shade structures for erythemal UV and UVA was observed. This is due to the shade being more below the actual shade structure and the lower levels of scattering at these smaller SZA, therefore less UV is entering the shade structures from the sides.

4. Conclusions

The entire shade environment needs to be carefully considered before a shade structure is constructed. The side openings of a shade structure have a direct influence on where the shade is located and the level of scattered UV in the shaded area. UV exposures measured in this research illustrate the decrease in scattered UV beneath specific shade structures by the use of two types of side-on protection, polycarbonate sheeting and vegetation. Measurements conducted in the shade of a scale model shade structure during summer and winter showed significant decreases in scattered UV levels of up to 65% less for summer and up to 57% less for winter when polycarbonate sheeting was added to the northern and north-eastern sides of the shade structure compared to measurements without polycarbonate sheeting. Measurements conducted in the shade of four shade structures with various amounts of evergreen vegetation covering different sides, showed that for Australian conditions, vegetation situated on the northern, western and south-western sides was the most effective at decreasing the scattered UV in the shade. Polycarbonate sheeting is useful for locations and SZA's where winter warmth is desirable, and vegetation is valuable for locations and SZA's where a cooling effect is required. Adding suitable vegetation and/or polycarbonate sheeting to specific sides of shade structures can significantly reduce scattered UV in the shade compared to shade structures that do not utilise any side-on protection. However, side-on protection is of little use if the positioning of the shade structure is inadequate. The positioning of the shade structure in respect to full sun activities is of key importance particularly where these activities involve infants and children. For example, when children are playing weekend sport in the mornings, the shade structure with the appropriate side-on protection needs to be positioned on the eastern side of the sports field. Conversely, for afternoon sport the shade structure with appropriate side-on protection needs to be positioned on the western side of the field.

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Table 1. Anatomical facial distribution of shade ratios beneath the model shade structure for summer and winter.

	Summer (Exposure shade ratios)				Winter (Exposure shade ratios)			
Facial Site	No PC	Bronze	Grey	Clear	No PC	Bronze	Grey	Clear
top of head	0.4	0.3	0.2	0.2	1.4	1.2	0.7	0.6
forehead	4.0	2.2	1.5	2.4	5.6	3.7	2.5	4.5
bridge of nose	4.8	2.2	3.5	2.7	6.4	3.1	5.6	4.2
lips	6.0	3.3	4.8	4.0	7.6	4.6	5.4	4.8
cheeks	5.1	3.0	3.0	3.2	4.3	2.9	4.2	4.2
ears	4.6	2.8	3.0	3.2	5.7	3.0	5.5	4.8
neck	6.7	4.1	3.4	4.4	8.5	4.7	5.7	5.3
back of head	5.3	2.7	1.5	2.7	5.9	2.9	4.9	5.1
eyes	4.2	2.3	1.9	2.9	5.0	4.2	4.5	4.0

Table 2. Summary of the maximum and minimum erythemal UV exposures observed in the shade of the four shade structures with varying degrees of surrounding vegetation.

Structure	Exposure (MED/10 min) max	min
□	0.14	0.09
Δ	0.10	0.03
○	0.08	0.01
∗	0.11	0.03

Figures

Figure 1. The half-size scale model and the clear tint polycarbonate sheeting attached to two sides.

Figure 2. The manikin head forms used and some of the anatomical facial dosimeter sites.

Figure 3. Dosimeter calibration curve.

Figure 4. The spectral transmission properties of the three types of polycarbonate sheeting used in the research.

Figure 5. Maximum UV exposures observed from the horizontal and vertical planes beneath the four shade structures, (a) □ ,(b) Δ, (c) O, (d) ∗, compared to full sun (◆) (right axis).

Figure 1.

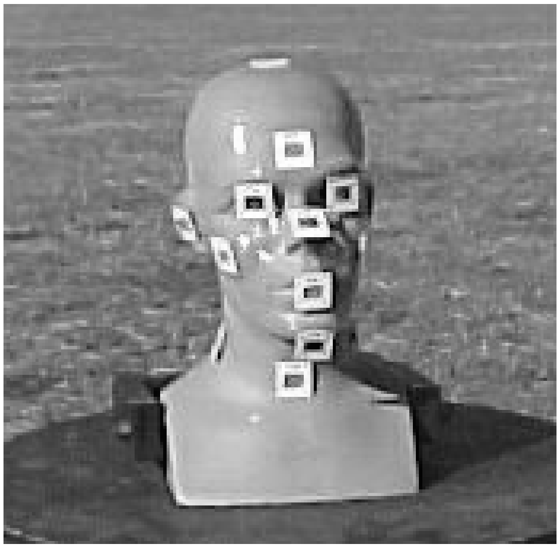


Figure 2.

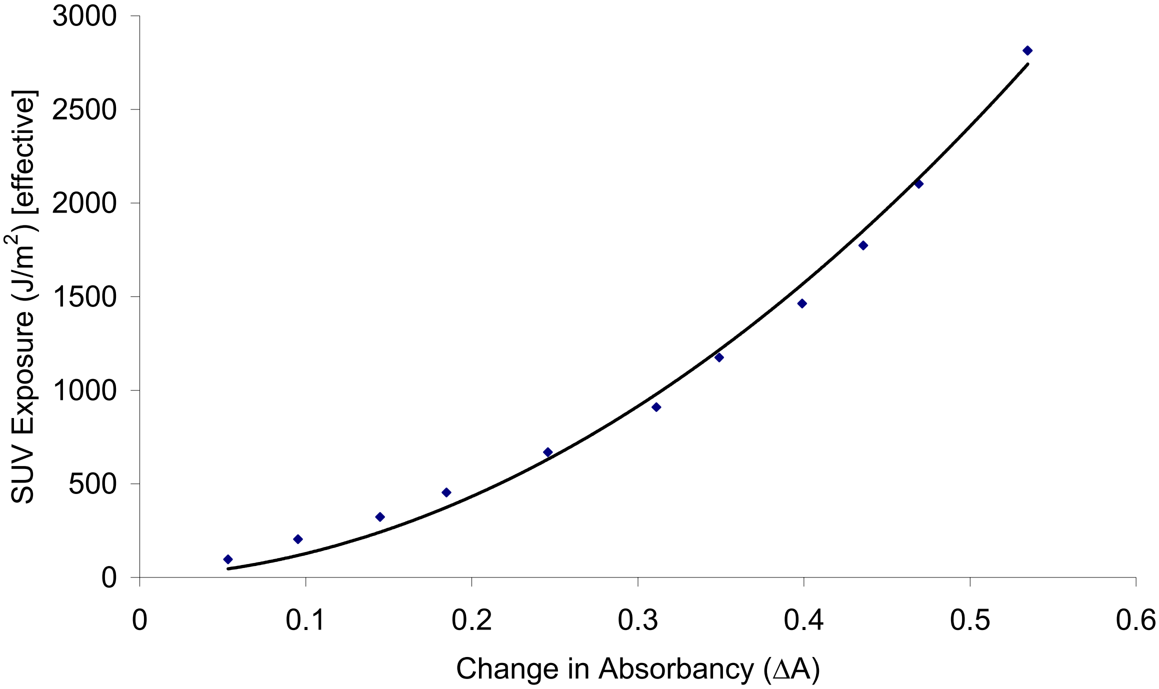

3000
2500
2000
1500
1000
500
0
SUV Exposure (J/m2) [effective]
0
0.1
0.2
0.3
0.4
0.5
0.6
Change in Absorbancy (ΔA)

Figure 3.

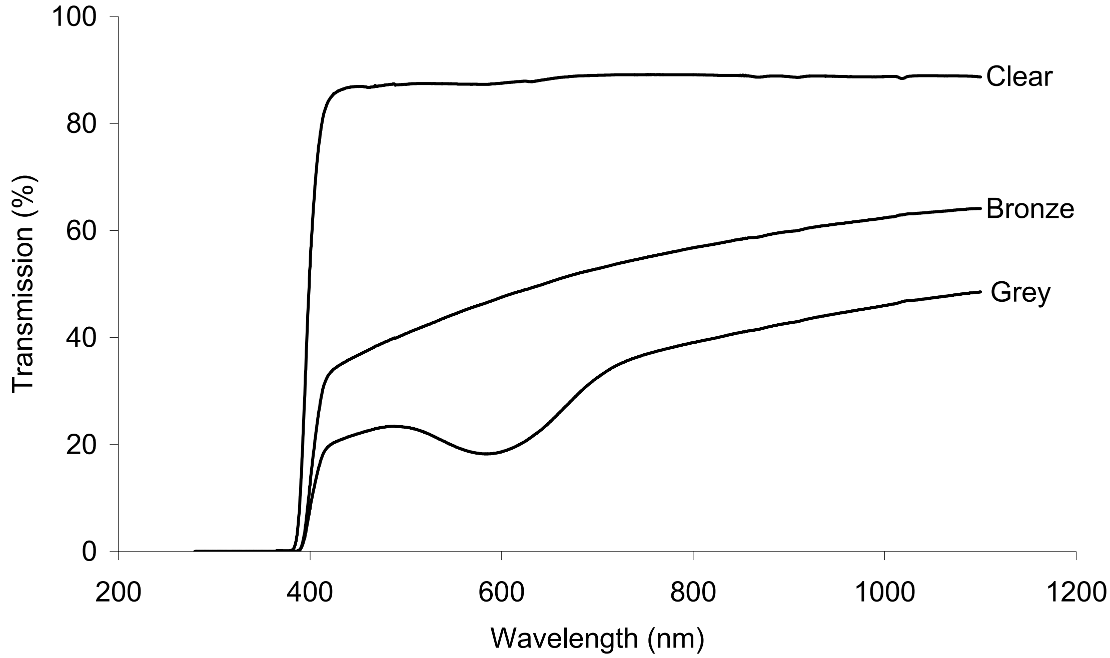
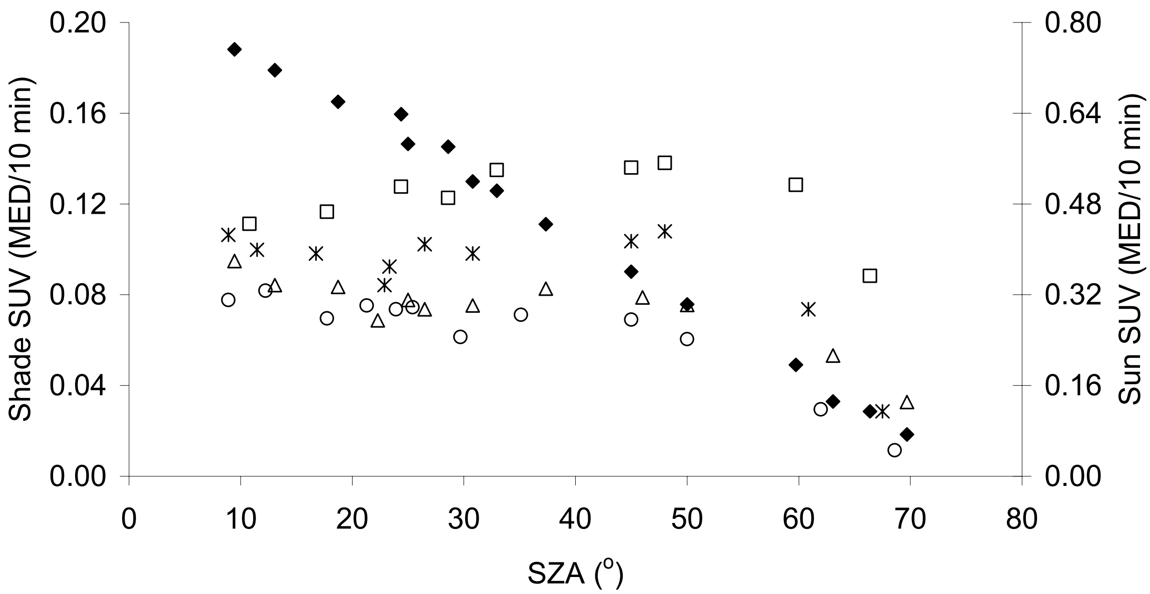

100
80
60
40
20
0
Transmission (%)
200
400
600
800
1000
1200
Wavelength (nm)
Clear
Bronze
Grey

Figure 4.

(a)


0.20
0.16
0.12
0.08
0.04
0.00
Shade SUV (MED/10 min)
0.80
0.64
0.48
0.32
0.16
0.00
Sun SUV (MED/10 min)
0
10
20
30
40
50
60
70
80
SZA (o)

(b)

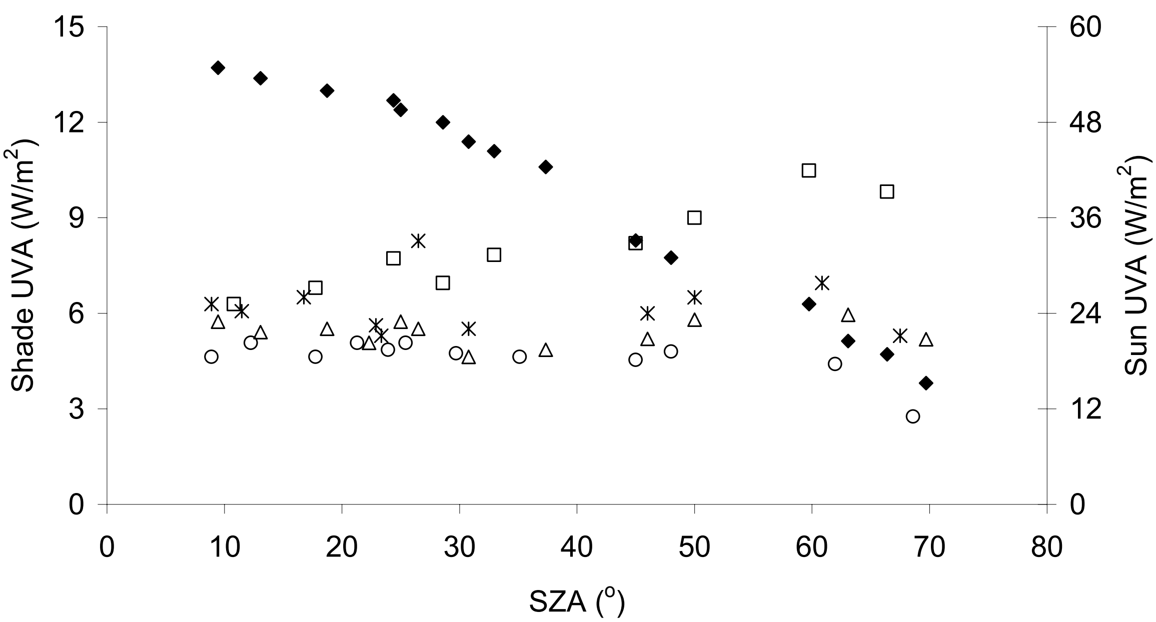

15
12
9
6
3
0
Shade UVA (W/m2)
60
48
36
24
12
0
Sun UVA (W/m2)
0
10
20
30
40
50
60
70
80
SZA (o)

Figure 5.

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