Spectral UV in public shade settings

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Abstract

The protective nature of specific shade environments was investigated by measuring the spectral UV in the shade for the three planes (horizontal, 45^{o} and vertical) and comparing this to that on a horizontal plane in full sun. Spectral UV irradiance measurements were made under clear sky conditions at a sub-tropical Southern Hemisphere site. The solar UV in the shade of a shade umbrella, covered verandah, covered sand pit and covered walkway were measured for an increasing solar zenith angle, between March and August, for the times of 11:30 am - 12:30 pm and 2:30 pm - 3:30 pm. The UPF's provided ranged from 1.4 to 10. This research shows that there is sufficient UV in the shade to cause erythema on the human body in a short period of time. For the shade umbrella placed on dry grass the time able to be spent in the shade in the middle of the day before experiencing mild erythema increased from 35 to 60 minutes as the solar zenith angle increased from 33^{o} to 52^{o}. Erythemal UV levels in the shade of a northern facing covered verandah, with trees in close proximity, were approximately up to five times less than the erythemal UV beneath the shade umbrella that had no surrounding trees. Shade structures must be given careful consideration when construction occurs. Even though the UV transmission through the materials may be very low, it is the construction of the entire shade setting that determines the exposure beneath the shade structure.

Keywords: Diffuse; UV; Shade structures; Erythema

1. Introduction

Excessive and repeated exposures to solar UV radiation have been linked to the induction of skin cancers, skin damage, premature skin ageing and wrinkling, and sun related eye disorders [1,2]. Incidence and mortality rates due to skin cancer in Australia are amongst the highest in the world, with two out of three Australians developing some form of skin cancer in their lifetime [3,4]. A report by Armstrong [5] estimates that the direct health care costs of all types of skin cancer in Australia amount to $734.9 million per year and the indirect costs in the form of sick leave and foregone earnings are in the region of $1.395 billion per year. Personal UV exposure is due to sunlight received as both direct and diffuse UV (UV that has been scattered by the atmosphere and the environment) radiation. The diffuse component may be up to 50% or higher [6]. This diffuse UV constitutes a significant contribution to the UV exposure to human eyes and skin as is it is incident from all directions and difficult to minimize with the usage of hats, tree shade and shade structures [7,8].

Behavioural influences determine the amount of UV exposure the body receives, be it from suntanning, sun protection practices or others. It has been shown that subjective comfort has a determining influence on the rates of sunburn, with people exposing more and more skin as they become hotter due to rising ambient temperature levels [9]. However, people will also stay out of the sun when the temperatures reach extreme levels where discomfort occurs.

As people become better informed about the damaging effects of UV, they seek shaded environments (for example, trees, shade umbrellas, covered verandahs) to reduce UV exposure levels [10]. Parisi et al [8] conducted research into the efficiency of tree shade in the reduction of biologically effective radiation. This study found that over a summer period approximately 60% of the erythemal UV in the shade was due to the diffuse component. Their data also showed that the amount of diffuse UV in tree shade remained relatively constant for varying times of the day, but the diffuse UV in the full sun showed a decrease from morning to noon and then an increase from noon to afternoon [8]. Parsons et al [11] found that tree shade that offered no side-on protection did not provide adequate protection from scattered UV. Moise and Aynsley [10] carried out direct broadband measurements underneath previously existing shade structures and found that dense foliage provided the greatest shade coverage. No research has measured the UV spectrum under public shade structures. This research compares the UV spectrum beneath four common shade structures with that of the total solar UV for relatively cloud free sky conditions and changing solar zenith angle. The months of March to August (autumn and winter) were chosen, because, it is expected that there is a higher proportion of diffuse UV in the shade caused by an increasing solar zenith angle.

2. Materials and Methods

2.1. Shade structures

Four different shade structures were employed in this research, and were located at the University of Southern Queensland (USQ), Toowoomba (27.5°S), Australia. Four structures were chosen so the relatively broad range of shade used by the public could be investigated. The structures were a shade umbrella, a covered verandah, a covered sand pit and a covered walkway. Details of the shade structures were as follows:

- The shade umbrella used for this setting was set up on a sports oval, and at least 20 meters from any other shade. The ground cover was dry grass with an albedo of approximately 4%. The umbrella diameter was 1.8 m and a height at the apex of 2.1 m. This structure was chosen as people watching a sporting event of some kind often shade themselves in this way from the sun’s heat and direct UV rays;
- The covered verandah of a building was used as a shade setting. A number of trees are located near this site and therefore have some influence over the scattered UV levels in the shade. The verandah covering of galvanized iron was approximately 7.0 m long, 1.5 m wide from the building wall and the eaves were 2.5 m high. This was chosen because the verandah of a building is a popular place to seek shade;
- A sand pit located at the eastern end of a building used as part of a childcare centre. Trees, shrubs and the building are located near the structure. The albedo of the sand was approximately 0.1. The sand pit covering was a closely woven polymer and was approximately 3.0 m high at the apex and 2.0 m high at the eaves, and the width of the structure was 2.6 m. Sand pits are commonplace at most childcare centres, with toddlers playing in the sand whenever possible;
- The covered walkway is situated between buildings. The height of the walkway was approximately 4.0 m, the depth 2.5 m, length 6.0 m, and with an east/west path. This was selected because covered walkways are very common between buildings, especially in inner-city areas and universities.

2.2. Spectroradiometric measurements

A scanning spectroradiometer fitted with a 15 cm diameter-integrating sphere (model OL IS-640, Optronics Laboratories, Orlando, FL, USA) that can be manually orientated was employed. The integrating sphere can be orientated at any angle between pointing directly upwards and pointing directly downwards. For this research, the integrating sphere was 1.0 m above ground level. The spectroradiometer has a double holographic grating (1200 lines mm^{-1}) monochromator (model DH10, Jobin-Yvon, France) connected to a R212 photomultiplier tube (Hamamatsu Co., Japan) temperature stabilized by a Peltier cell temperature controller to $15.0 \pm 0.5^{o}C$.

Prior to each series of scans, the spectroradiometer was wavelength calibrated against UV mercury spectral lines and absolute irradiance calibrated against a quartz tungsten halogen lamp (250 W) operated at 9.500 ± 0.005 A d.c. and with a calibration traceable to the National Standards Laboratory at the CSIRO, Lindfield**.** The current was supplied to this secondary standard lamp from a regulated power supply (model PD36 20AD, Kenwood).

The solar UV spectrum and UV spectrum in the shade of the four shade structures were recorded with the spectroradiometer for clear solar disc conditions for each of the four different shade environments. For each shade setting and each of the two sky conditions, measurements were at two specific periods of the day (11:30 - 12:30 EST, noon and 14:30 - 15:30 EST, afternoon) and for increasing solar zenith angle during March to August of 2001. During this time the solar zenith angles (SZA) ranged from 33^{o} to 52^{o} for noon and 53^{o} to 65^{o} for the afternoon period. Before each measurement, the spectroradiometer was levelled to ensure that the input aperture of the integrating sphere was on a horizontal plane. For each of the shade settings, the UV spectrum was measured in the approximate centre of the shadow cast by the shade structure. The spectrum was scanned from 280 to 400 nm in 1 nm increments, with each scan taking approximately 45 s to complete. Over the period of the scans the SZA did not change significantly. The only exceptions were days when the atmospheric or cloud conditions changed in a short period of time and it was necessary to wait for the solar disc to become clear of cloud.

The measuring sequence was: measure the UV spectrum in the sun on a horizontal plane (with the entrance aperture of the integrating sphere directed upwards) at a distance of 20 m or as far as possible from the shade; measure the UV in the shade; and then measure the UV spectrum in the sun a second time. For each of the shade settings, the UV spectrum incident on a vertical plane, horizontal plane and on a plane 45^{o} to the vertical was measured. For the shade umbrella and sand pit, the measurements on the vertical and 45^{o} planes were directed towards the direction of the sun; for the covered verandah and covered walkway these measurements were aimed in a northern direction. The time difference between the sun and shade measurements was as short as possible.

The visible irradiances were measured with a LUX meter (model EMTEK LX-102, supplier, Walsh's Co., Brisbane, Australia) to allow a comparison with UV irradiances. The visible irradiances were measured in the full sun and then in the shade for both seasons and both times of the day. The LUX meter was at approximately the same height as the integrating sphere aperture height, and levelled on a horizontal plane.

2.3. Shade umbrella material transmittance

Both shade umbrella and sand pit coverings were made from various woven materials, therefore the transmission through each of these had to be measured and taken into account. The UV transmittance of the shade umbrella that was used was determined with the scanning spectroradiometer on four separate occasions, scanning the incoming spectrum from 280 to 400 nm on a relatively cloud free day. The solar spectral UV irradiance, $S(\lambda)$ was measured in increments of 1 nm and then the fabric of the shade umbrella was placed directly over the opening of the integrating sphere in a stretched state similar to that when fully deployed. The spectral irradiance of UV passing through the fabric, $S_T(\lambda)$, was then measured in increments of 1 nm. The time difference between the two sets of measurements was approximately 5 minutes. Consequently, the change in solar UV irradiance was minimal. The measurements were made on several different days in order to obtain an average value of the transmittance. The transmittance was calculated as the ratio of $S_T(\lambda)$ summed over the waveband 280 to 400 nm divided by the sum of $S(\lambda)$ over the same waveband.

2.4. Sand pit cover transmittance

Due to the fixed nature of the shade structure over the sand pit being too high for the integrating sphere, it was not feasible to employ the scanning spectroradiometer to measure the transmittance of the covering material. Consequently, the UV irradiances were measured in the shade with a radiometer (model 3D V2.0, Solar Light Co., Philadelphia, PA, USA) fitted with a UVA detector and an erythemal UV (UVery) detector. The radiometer was calibrated to the spectroradiometer with the solar UV as the source. The transmittance measurements were made on a relatively cloud free day by placing the entrance optics of the radiometer directly beneath the shade cloth (approximately 2.3 m above the ground), facing directly towards the sun. The direct full sun measurements were made by placing the radiometer at the same height, same orientation and approximately 1.5 m from the shade structure. The transmittance is the ratio of the shade measurements to the full sun measurements.

2.5. Biologically effective uv

Weighting of the spectral irradiance, $S(\lambda)$, with the action spectrum for a particular biological process, $A(\lambda)$, allows for the biologically effective UV irradiance, UVBE, to be calculated at 1 nm increments:

$$UVBE = \int_{UV} S(\lambda) A(\lambda) d\lambda \qquad (1)$$

For this research, the erythemal [12], photokeratitis [13] and fish melanoma [14] action spectra have been employed. Linear interpolation has been used for points not present in the action spectra. No action spectrum exists for melanoma in humans, but the fish melanoma action spectrum may possibly provide an indication of the wavelengths effective in human melanoma [15].

3. Results

3.1. Biologically effective uv

The mean UV irradiance through the fabric of the shade umbrella was found to be 0.24 (W/m^2) with a range of ± 0.11 (W/m^2) for total UV, and 0.028 ± 0.030 (MED/h) for erythemal UV (where an MED, or minimum erythemal dose, is equivalent to 200 Jm^{-2} [16]). This equates to a percentage transmission of approximately 0.5 % for total UV and 0.9 % for erythemal UV. The erythemal UV through the material over the sand pit was 0.18 ± 0.01 (MED/h), equating to a transmission of 4.8%. The UVA was 0.70 ± 0.10 (W/m^2), which is a transmission of 2.1%. No spectral dependency was observed for the transmission through the shade umbrella fabric.

Spectral irradiances taken beneath the shade umbrella around noon on 14 May have been weighted by the erythemal, photokeratitis and fish melanoma action spectra (Fig. 1a) and are shown in Fig. 1(b) and 1(c). Fig. 1(b) and 1(c), are shown from 300-400 nm due to noise in the data and the solar irradiance being indistinguishable below 300 nm. The fish melanoma action spectra shows that there is a significant biological response over the UVA (320-400 nm) and UVB (280-320 nm) waveband, whereas from Fig. 1 it can be seen that the erythemal and photokeratitis UVBE are more biologically effective in the UVB waveband.

3.2. UV under different shade structures

Horizontal UVBE ratios are shown in Fig. 2 as a function of SZA, for clear sky conditions. The shade structures are plotted against each other to show how the levels of UV compare beneath each shade structure.

Fig. 3 shows the UVBE for the four shade structures, at the two measurement times and for the three orientations, weighted for the biological responses of erythema and photokeratitis. The shade umbrella recorded the highest UVBE of all shade structures, with the horizontal plane receiving the greatest levels of erythemal UV.

3.3. Visible light intensity and solar zenith angle

Fig. 4 shows the visible light intensity measurements that were collected during the course of the spectral measurements. These are plotted against the changing SZA to show how the intensity of the full sun changes over the course of a number of months and how this affects visible light in full sun and in shade. For full sun measurements, the intensity ranged from 130000 lux to 51500 lux. The intensities in the shade did not show such a large variation overall, but variation between structures was observed. The shade umbrella ranged from 9000 to 6500 lux, whereas the three other structures ranged from 5500 to 1800 lux. In the full sun, there is a dependence of the Lux on SZA, but there was no obvious dependence in the shade.

3.4. Ultraviolet protection factor (UPF)

Spectral shade ratios were used to obtain the ultraviolet protection factor (UPF) for a shade structure. Refer to table 1 for the UPF’s of each shade structure for changing times and seasons. Generally, the UPF for the shade decreased as the SZA increased; this is due to the larger relative proportion of diffuse UV as a result of the larger SZA. Table 2 shows average times able to be spent beneath each shade structure before receiving 1 MED, for noon and afternoon in autumn and winter. Exposure times were calculated based on the plane that received the highest erythemal UV exposure.

4. Discussion

The spectral UV in four public shade settings has been measured. The action spectra used are normalized, so the plots provide the change with wavelength for each effect, rather than an absolute quantity to compare between different action spectra. For the photokeratitis action spectrum no response is available in the literature past 316 nm. Measurement of the UV spectrum provides the advantage over broadband measurements in that the UVBE can be calculated for any biological process. The UVBE in the shade of the shade umbrella showed a clear decrease for both time periods as the SZA increased. The covered verandah showed no significant differences in UVBE levels. The UVBE in the shade of the sand pit on the 45^{o} and horizontal planes showed a definite increase for the noon and afternoon periods as the seasons progressed, but a decrease was observed when the noon measurements were compared to the afternoon. The UVBE irradiances taken at noon beneath the covered walkway showed no significant change, although a slight increase for the 45^{o} plane was observed as the seasons advanced. The afternoon measurements showed a definite increase as the seasons changed for the 45^{o} and vertical planes, but the horizontal plane values remained virtually unchanged.

The shade umbrella received the highest levels of UVBE in the shade for both seasons. Compared to full sun, the erythemal UV in the shade reached levels of approximately 81% and 84% for photokeratitis. The covered verandah showed the lowest amount of total UVBE in the shade with values up to 15% for erythemal and 14% for photokeratitis. UVBE in the shade of the sand pit was up to approximately 37%

for both erythemal and photokeratitis. For the covered walkway, the maximum UVBE in the shade was approximately 63% for erythemal and 71% for photokeratitis. Variation between some of the measurements at similar SZA's can be attributed to variations in the amount of diffuse radiation due to clouds low in the sky, even though the solar disc was clear. UVB percentages in the shade were marginally higher than UVA, when compared to the full sun. This is due to the higher Rayleigh scattering at the shorter wavelengths. This is also apparent with the visible waveband as the changing SZA affected the visible light intensities more than the UV. The full sun visible intensities continuously decreased as the SZA increased, whereas the shade measurements remained relatively unchanged. The visible light intensity measurements show that there is no correlation between visible irradiances and UV in the shade.

The UPF's ranged from 1.4 to 10, with a general decrease from noon to the afternoon. The only exception was for the covered walkway from noon to the afternoon, which showed no change for the winter period. The amount of time able to be spent beneath each shade structure before experiencing mild erythema generally increased as the seasons progressed, except for the winter period beneath the sand pit covering, where it actually decreased. This was unexpected, and may be due to the albedo of the sand increasing at the larger SZA's, because more of the sand was becoming exposed to the full sun. It is also expected that these UPF's will be reduced even further on cloudy and partially cloudy days, as the diffuse UV is higher on these days.

Shade structures that have trees, shrubs or buildings in close vicinity have UV levels in the shade significantly lower than those with no surrounding shading objects. The highest UVBE levels were encountered beneath the shade umbrella, especially for the smaller SZA. The increasing SZA decreases the difference in UV levels between shade structures, due to the increased atmospheric path length of the radiation. As a result there is more diffuse UV and therefore the shade is not as effective. The shade umbrella measurements were conducted on grass and it must be stated that the use of an umbrella on sand would increase the diffuse UV because of the high albedo encountered over sand.

This research has shown that, shade does not provide full protection against UV radiation. Even though the transmission of UV radiation through the shade materials may be very low, it is the diffuse UV component that must be taken into account. It has also proved that the proportion of diffuse UV increases under shade structures as the solar zenith angle increases. People seeking a shaded environment for an extended amount of time need to employ a combination of UV protective practices to minimize the UV exposures to human skin and eyes. Furthermore, the construction of shade structures requires further research if the higher relative proportion of diffuse radiation at the shorter wavelengths is to be reduced.

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Table 1. Summary of Ultraviolet Protection Factors (UPF's) for each shade structure for relatively cloud free skies.

	UPF's			
	Autumn		**Winter**	
	Noon	**Afternoon**	**Noon**	**Afternoon**
Shade Umbrella	1.7	1.7	3.3	1.4
Covered Verandah	10.0	6.7	6.7	5.0
Covered Sand Pit	10.0	5.0	5.0	3.3
Covered Walkway	10.0	2.0	2.5	2.5

Table 2. Summary of average times able to be spent in the shade, of the different shade structures, before receiving mild erythema.

	Exposure times (mins)			
	Autumn		**Winter**	
	Noon	**Afternoon**	**Noon**	**Afternoon**
Shade Umbrella	35	35	60	60
Covered Verandah	170	175	230	277
Covered Sand Pit	155	222	90	166
Covered Walkway	105	101	125	81

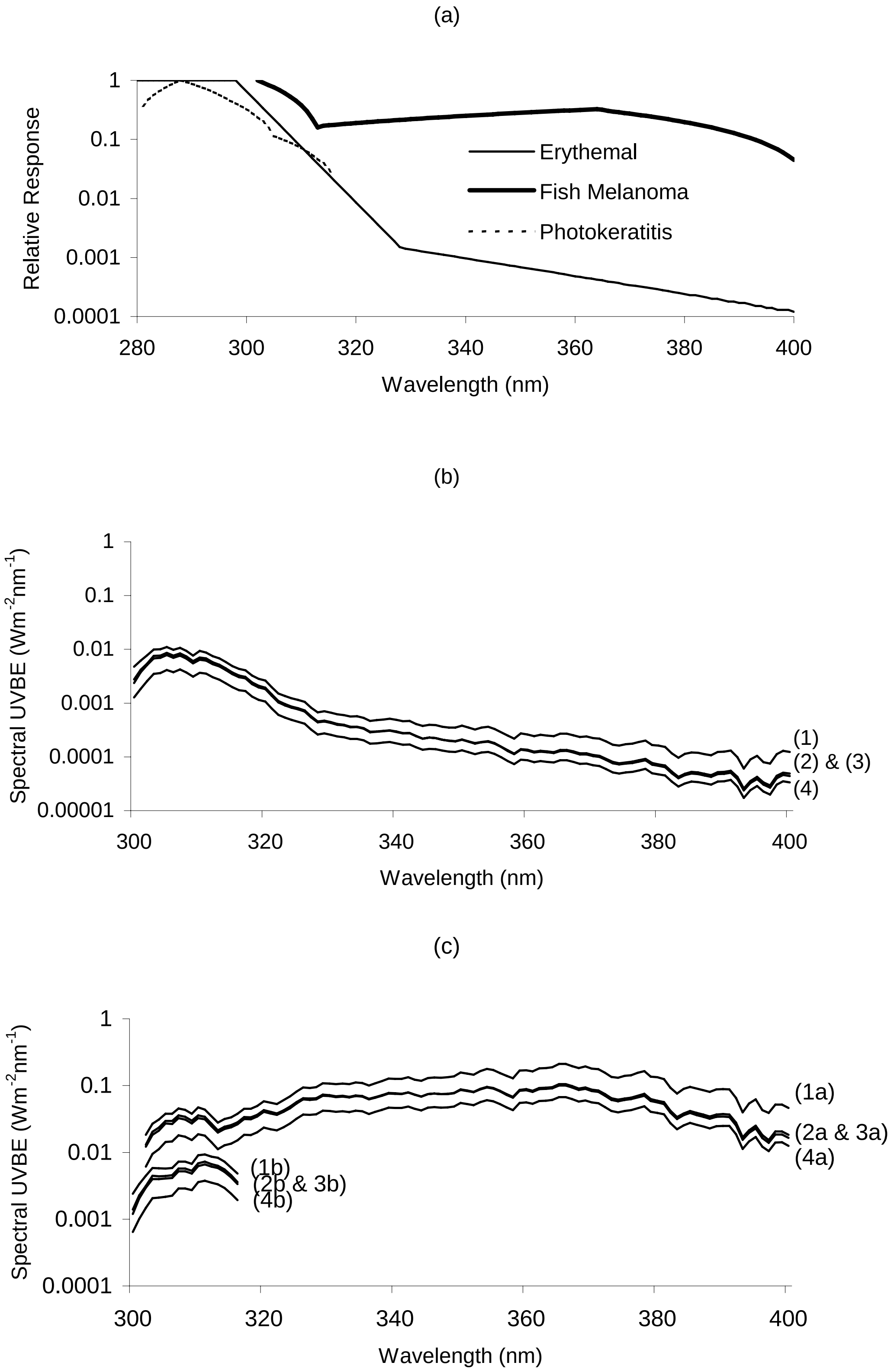
Figure Captions

Figure 1. The relative responses (a) of the erythemal, photokeratitis and fish melanoma action spectra. Spectral irradiances for the shade umbrella taken on 14 May 2001, weighted by the erythemal (b), photokeratitis and fish melanoma (c) action spectra. The UVBE is for full sun horizontal plane (1) and shade on a 45^{o} plane (2), vertical plane (3) and horizontal plane (4).

Figure 2. Horizontal UVBE shade ratios for each shade structure (shade umbrella ♦, covered verandah □, covered sand pit Δ, and covered walkway ●). The data are plotted against solar zenith angle. Ref refers to the corresponding full sun measurements.

Figure 3. Comparison of UVBE levels for both erythema and photokeratitis beneath the four shade structures for a relatively cloud free sky, three orientations and for noon and afternoon. Noon and afternoon measurements were conducted on either the same day or within a couple of days of each other. Graphs (a) and (c) are for autumn, and (b) and (d) are for winter.

Figure 4. The collected visible light intensities for full sun (□) and for shade beneath the shade structures (▲) versus the solar zenith angle (SZA).



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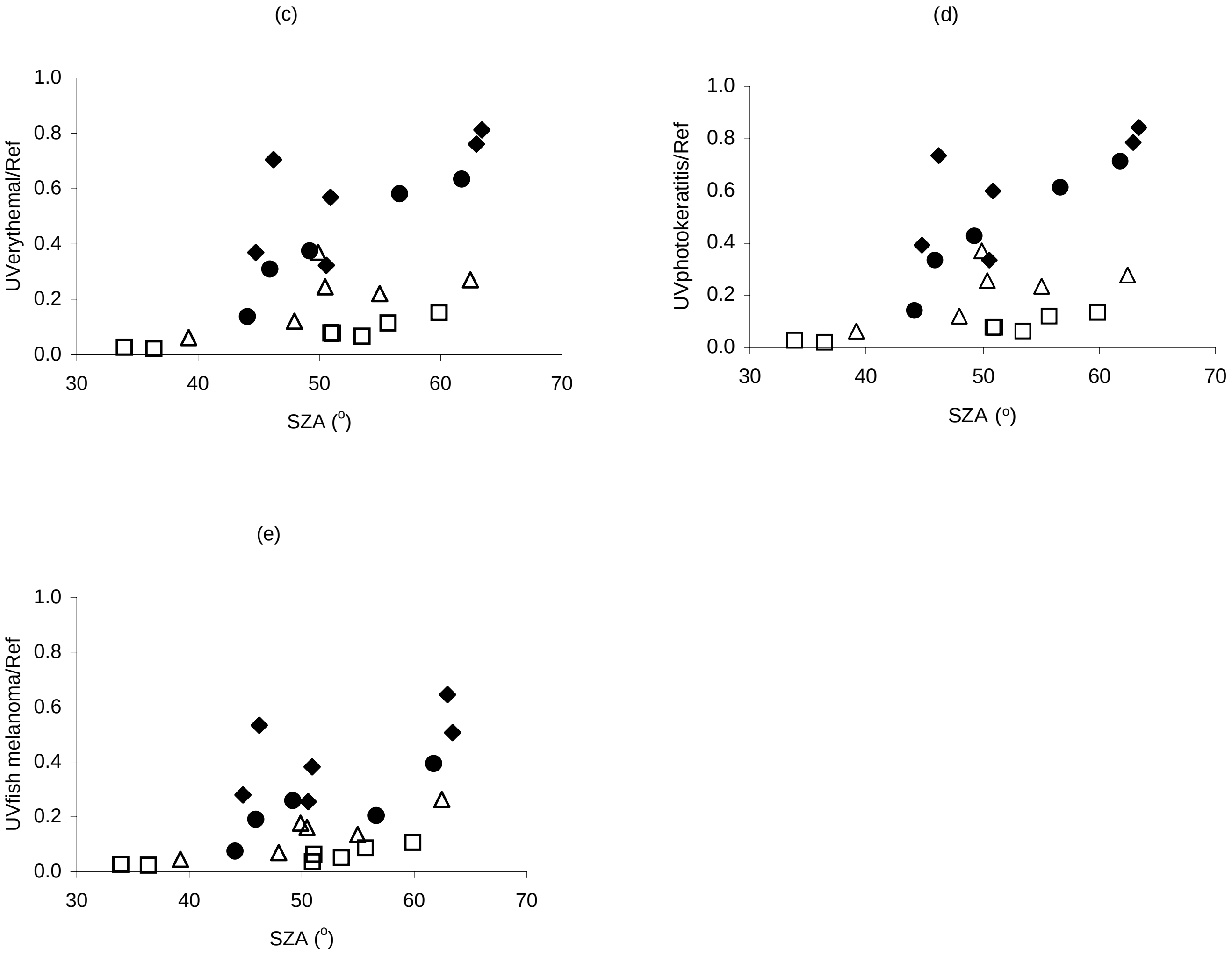

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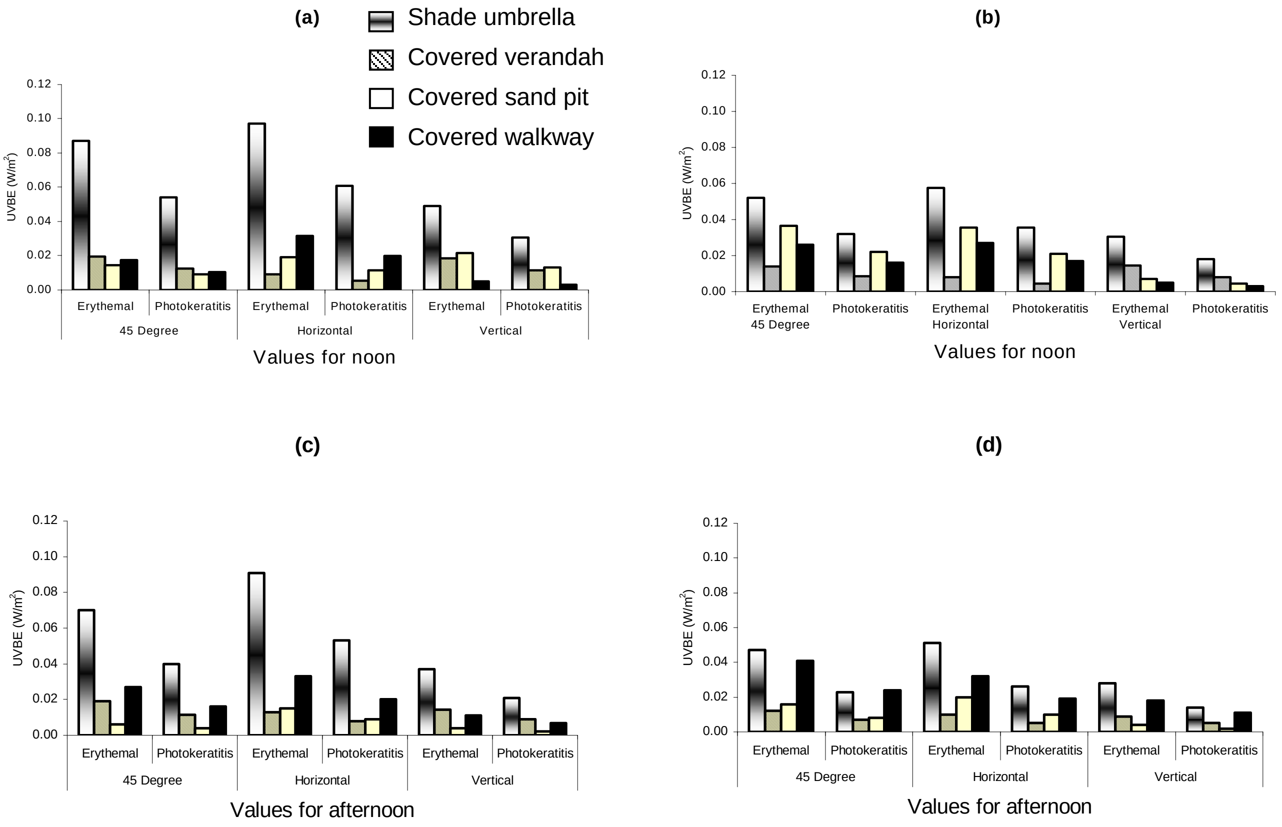

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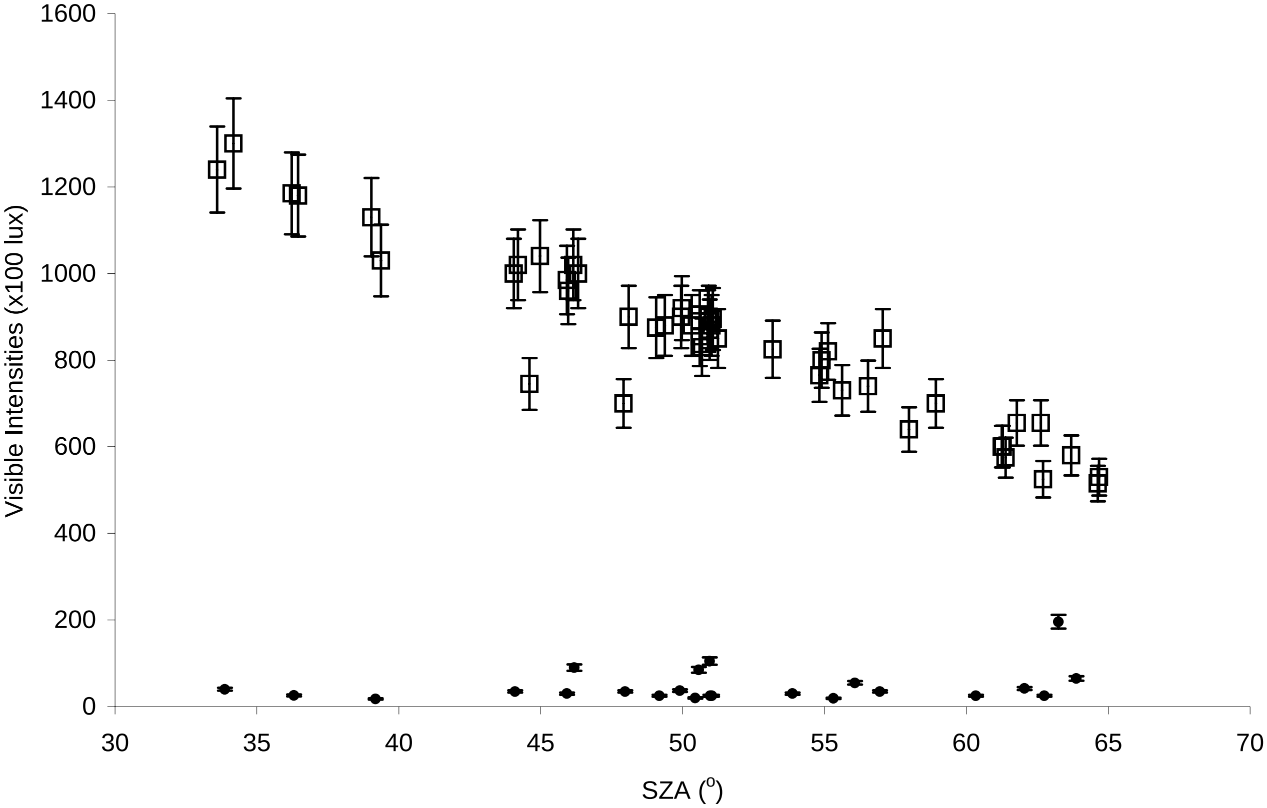

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