Development of an Improved Shade Environment for the Reduction of Personal UV Exposure

by

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A thesis submitted for the degree of Doctor of Philosophy

to the University of Southern Queensland

Department of Biological and Physical Sciences

2005

Abstract

The research from this project has quantified the solar UV environment beneath and surrounding typical local council public shade structures. The effects of changing seasons, atmospheric conditions, structural modifications and surrounding plant life on diffuse UV have been quantified. Strategies to improve current shade structures, so as to significantly reduce the levels of diffuse UV reaching the human body in the shade, have also been developed. For the shade structures used in this research it was found that ultraviolet protection factors ranged from 1.5 to 18.3 for a decreasing solar zenith angle. Correlations have been found relating diffuse erythemal UV to UV in the shade for clear skies and a changing solar zenith angle. The effect of changing atmospheric ozone levels on diffuse erythemal UV levels has been quantified. UV exposures were assessed for a decrease in scattered UV beneath specific shade structures by the use of two types of protection, namely, side-on polycarbonate sheeting and evergreen vegetation. Broadband radiometric and 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 blocking different sides, showed that adequate amounts and positioning of vegetation decreased the scattered UV in the shade by up to 89% when compared to the shade structure that had no surrounding vegetation. This research shows that major UV reduction could be achieved by the 'shade creation and design industry', and that shade guidelines should be updated as soon as possible.

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Glossary of Terms and Abbreviations

ΔA	Measured change in optical absorbency of a polysulphone dosimeter.
Actinic radiation	Radiation that can produce a photochemical reaction.
Action Spectrum	Used to show the relation between the wavelength of the irradiating photons and the effect on certain biological processes.
Aerosols	Tiny particles suspended in the atmosphere.
Albedo	Ratio of upwelling radiation to incident radiation.
Altitude Effect	The percentage increase over 1000 m relative to the lowest measurement site.
BCC	Basal Cell Carcinoma.
Diffuse radiation	Radiation that is scattered and reflected, namely not coming directly from the source.
Direct Radiation	Radiation coming directly from the source.
Diurnal	Belonging to the daylight period.
Dobson Unit	One Dobson unit (DU) is defined as 0.01 mm ozone thickness at standard temperature and pressure.
Dosimeter	A device used to measure radiation exposure.
Dosimetry	The technique of applying dosimeters for measuring UV radiation.

Earth-Sun Distance	149,597,893 ± 5,000,000 km.
Erythema	Reddening of the skin due to UV radiation exposure often referred to as sunburn.
Global Radiation	Total radiation consisting of direct radiation and diffuse radiation.
Minimum Erythemal Dose	Abbreviated to MED and described as the minimum exposure to UV radiation required to cause erythema (1 MED = 200 J/m^2).
MM	Malignant Melanoma.
Monochromatic	Electromagnetic radiation of a single wavelength.
NCPP	National Cancer Prevention Policy.
NMSC	Non Melanoma Skin Cancer.
Non-ionising Radiation	Radiation without enough energy to remove tightly bound electrons from their orbits around atoms (for example UV and visible radiation).
Ozone	A variation of oxygen molecule containing three oxygen atoms (O_3).
Polysulphone	A polymer that is often used as a dosimeter to measure UV radiation.
Radiometer	An instrument used to measure radiation over a broad waveband.
RAF	Radiation Amplification Factor
RB meter	Robertson-Berger meter, an instrument designed to measure

	erythemal irradiance.
SAD	Seasonal Affective Disorder.
SCC	Squamous Cell Carcinoma.
Solar Elevation	The angle of the sun from the horizontal.
Solar Zenith Angle	(SZA) The angle of the sun extending from the zenith.
Spectrophotometer	A device used to measure the optical absorbency of polysulphone at specific wavelengths.
Spectroradiometer	An instrument used to measure irradiance at specific wavelengths.
STP	Standard Temperature and Pressure. Conditions at sea level of 0^oC and 1 atmosphere.
Stratosphere	The layer of the earth's atmosphere containing the majority of the earth's ozone.
SUV	Erythemal UV
Troposphere	The layer of the earth in which humans live and also responsible for the majority of the earth's weather.
Turbidity	Haziness of the atmosphere due to aerosols.
UPF	Ultraviolet Protection Factor
UV	Ultraviolet radiation
UVA	320 – 400 nm
UVB	280 – 320 nm

UVC	100 – 280 nm
Vitamin D_3	A vitamin that is produced in the human body following exposure to specific UVB wavelengths.

Certification of Dissertation

I certify that the ideas, experimental work, results, analyses and conclusions reported in this dissertation are entirely my own effort, except where otherwise acknowledged. I also certify that the work is original and has not been previously submitted for any other award, except where otherwise acknowledged.

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Signature of Candidate Date

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Signature of Supervisor Date

Acknowledgements

I would firstly like to sincerely thank my supervisor, Dr Alfio Parisi, for his assistance and advice throughout my PhD research. I would also like to acknowledge the academic and technical staff of the Department of Biological and Physical Sciences of the University of Southern Queensland for their assistance and support throughout my PhD research. I would like to thank Dr Jeff Sabburg, Mr Oliver Kinder and Mr Graham Holmes for their technical assistance and advice.

Special thanks also go to my family and friends who have supported me throughout.

Publications, Conferences and Awards from this Research

Journal Articles (refer to Appendix D)

1. **Turnbull, D.J.** & Parisi, A.V. 2005, "Under cover of shade structures," submitted to *Medical Journal of Australia.*
2. **Turnbull, D.J.** & Parisi, A.V. 2005, "Seasonal changes in the personal distribution of erythemal UV beneath a public shade structure," submitted to *Environmental Health.*
3. **Turnbull, D.J.** & Parisi, A.V. 2005, "Understanding the diffuse component of the solar terrestrial erythemal UV," submitted to *Radiation Protection in Australasia*.
4. **Turnbull, D.J.** & Parisi, A.V. 2005, "The importance of the diffuse component of solar UV beneath shade structures," *Teaching Science, 51(1), 22-24.*
5. **Turnbull, D.J.** & Parisi, A.V. 2005, "Increasing the ultraviolet protection provided by public shade structures," *Journal of Photochemistry and Photobiology B: Biology,* 78(1), 61-67.
6. **Turnbull, D.J.** & Parisi, A.V. 2004, "Annual variation of the angular distribution of the UV beneath public shade structures," *Journal of Photochemistry and Photobiology B: Biology*, 76(1-3), 41-47
7. **Turnbull, D.J.** 2004, "How safe is a place in the shade," *Campus Review*, 14(12), 9.
8. **Turnbull, D.J.** 2004, "10th Congress of the European Society for Photobiology," *The Physicist*, 40(5), 137.

9. **Turnbull, D.J.**, Parisi, A.V. & Sabburg, J. 2003, "Scattered UV beneath public shade structures during winter," *Photochemistry and Photobiology*, 78(2), 180-183.

Conference Presentations (refer to Appendix E)

1. **Turnbull, D.J.** & Parisi, A.V. 2004, "Improving the Protective Efficiency of Shade Structures," *14th International Congress on Photobiology, Jeju, South Korea, 10-15 June, 2004.*
2. **Turnbull, D.J.**, Parisi, A.V. & Sabburg, J. 2003, "The Protective Nature of Public Shade Structures in Australia," *Australian Institute of Physics Postgraduate Night, Brisbane, 21 Oct, 2003.*
3. **Turnbull, D.J.** & Parisi, A.V. 2003, "UV Protection Provided by Public Shade Structures During Winter," *Annual Queensland Health and Medical Scientific Meeting, Brisbane, 25-26 Nov, 2003.*
4. **Turnbull, D.J.**, Parisi, A.V. & Sabburg, J. 2003, "UV Protection and Shade Structures," *10th Congress of the European Society for Photobiology, Vienna, Austria, 6-11 Sept, 2003.*

Awards and Grants

1. University of Southern Queensland Postgraduate Scholarship, 2003-2004.
2. Australian Institute of Physics, 2004 - $500 international conference travel assistance.
3. Australian Institute of Physics, 2003 - $500 international conference travel assistance.

4. European Society for Photobiology (ESP), 2003 – awarded a Fellowship of $770 to attend the 10th Congress of the European Society for Photobiology.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Australia has one of the highest rates of skin cancer incidence and mortality in the world, with an estimated two out of three Australians developing some form of skin cancer during their lifetime (ACCV, 1999; Roy and Gies, 2000, Giles et al, 1988). Skin cancer is considered the most common malignant neoplasm in Australia and the USA (Kricker and Armstrong, 1996).

UV radiation is a carcinogen and repeated exposure to sunlight is now widely accepted as the major environmental cause of skin cancer and sun related eye disorders in all skin types who are genetically predisposed (Longstreth et al, 1995; NHMRC, 1996; Carter et al, 1999; van der Leun and de Gruijl, 1993). UV-induced types of skin cancer include basal cell carcinoma (BCC), squamous cell carcinoma (SCC) and malignant melanoma (MM). Research shows that there is a clear relationship between repeated exposure of the skin to UV and the incidence of BCC and SCC (Urbach, 1997; MacKie, 2000). Although sunlight exposure is implicated in melanoma development, the relationship with exposure is not completely certain as melanoma is not generally located on highly exposed areas of the body (Setlow et al, 1993; Preston and Stern, 1992; Urbach, 1997). It is thought that intermittent severe exposures (severe enough to cause sunburn) are critical for UV-induced melanoma and that UV exposures in infancy are more dangerous than exposures later in life (Ambach and Blumthaler, 1993; Stanton et al, 2000). Although melanoma is generally a disease of adulthood, research has shown that children in Queensland, Australia, have the highest incidence rates of melanoma in the world (MacLennan et al, 1992). The latest research suggests that individuals receive less than 25% of their total lifetime UV radiation exposure by the age of 18 (Godar et al, 2003).

Personal UV exposure is due to sunlight received as both direct and diffuse UV radiation. Diffuse UV constitutes a significant contribution of 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 (Parisi and Kimlin, 1999a; Parisi et al, 2000a; Turnbull and Parisi, 2003). Behavioural influences also determine the amount of UV exposure the body receives, be it from suntanning, playing sport, gardening or other activities. 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 (Hill et al, 1992). 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 associated with exposure to UV, shaded environments will be sought to reduce UV exposure levels (Moise and Aynsley, 1999; Turnbull and Parisi, 2003). It is not often appreciated that people sheltering under trees or shade structures are exposed to a considerable amount of scattered UV radiation (Parsons et al, 1998, Turnbull and Parisi, 2003, Turnbull et al, 2003). While there are numerous guidelines for the design of various shade environments (e.g. DAUQ, 1995; 1996; 1997; 1999; AIEH, 1995), most forms of shade still offer people insufficient protection from UV radiation. Therefore, a need exists for more detailed research on the interaction of UV radiation with shade environments and subsequent ways to reduce personal UV exposure in the shade.

The economic burden of skin cancer on the Australian health system has been quoted by different sources to be anywhere from $103 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 (Armstrong, 1995; Carter et al, 1999; Marks et al, 1993). Research into improving shade structures has the potential to help decrease incidence and mortality rates and also public health care costs associated with skin cancer and sun related disorders.

1.2 Objectives

The objectives of this research program are as follows:

1. The quantification of solar UV irradiances beneath and surrounding local council public shade structures, that have not been previously investigated in this context;

2. To determine the effects on the UV radiation and biologically damaging UV in the shade of the structures in 1) above, due to changing seasons, cloud conditions, structural modifications, and surrounding plant life;

3. To develop ways to improve public shade structures so as to significantly reduce the levels of diffuse UV reaching the human body in the shade;

4. To develop a mathematical relation that can approximate the biologically effective UV irradiances in the shade of the shade structure based on the diffuse UV in full sun;

1.3 Thesis Outline

- Chapter 2 will give an overview of solar ultraviolet radiation, the interaction of UV with the Earth's atmosphere, direct and diffuse UV, the biological effects for humans and the idea of action spectra to relate irradiance to biologically effective exposure.
- Chapter 3 will present an outline of past research related to solar radiation in the shade.
- Chapter 4 will detail the instrumentation and shade structures used for this current research and also the techniques used to measure the solar UV radiation at a sub-tropical site.
- Chapter 5 will provide results and expressions of long term measurements of global and diffuse solar UV radiation.
- Chapter 6 will present the results of the UV measurements beneath specific public shade structures and UV measurements beneath a modified scale model shade structure.
- Chapter 7 will discuss the conclusions drawn from the results provided in chapters 5 and 6, and recommendations to public health policy regarding shade structures.

CHAPTER 2

SOLAR ULTRAVIOLET RADIATION AND HUMANS

2.1 Introduction

The health effects of solar UV radiation vary significantly, from assisting calcium absorption in humans to the severe degradation of body tissue. The good effects are relatively few, but they are essential to a persons well being. Research has shown that exposure to small amounts of solar UV radiation are beneficial for the human body and important in the production of vitamin D_3, whereas excessive exposure to solar UV radiation is known to cause erythema, skin aging, skin cancer and sun-related eye disorders (Glerup et al, 2000; Terenetskaya, 2000). This chapter will discuss solar UV radiation, its interaction with the Earth's atmosphere and the subsequent biological effects for humans.

2.2 Solar UV Radiation

In 1801, Johann Ritter discovered that sunlight delivered chemically active (actinic) radiation just beyond the violet end of the electromagnetic spectrum (Gillespie, 1970). UV radiation is a non-ionising radiation that is situated between the visible and the soft X-ray wavebands with a wavelength range from 100 to 400 nm. The International Commission on Illumination (CIE) defines the UV wavebands as: UVC (100 - 280 nm), UVB (280 – 315 nm) and UVA (315 – 400 nm). However, a large proportion of the UV researchers define the UVA and UVB waveband boundary as 320 nm due to the significant effect at the longer wavelengths.

2.2.1 Global and Diffuse UV

The collection of the entire solar UV radiation waveband incident on the Earth's surface is described as global radiation and is comprised of both a direct and diffuse component (Turnbull et al, 2003). The direct component of global UV is incident directly from the sun and it is easy to minimize by simply blocking its path. Therefore, diffuse UV is definable as the global UV minus the direct component. Diffuse UV is mainly caused by atmospheric scattering and is difficult to minimize because it is incident from all directions (Toomey et al, 1995; Turnbull et al, 2003). For a completely overcast sky, all radiation is considered as diffuse radiation (Blumthaler, 1993). The ratio of diffuse UV to global UV varies with both wavelength and solar elevation for clear sky conditions (Blumthaler, 1993). These differences are caused by Rayleigh scattering ($\propto \frac{1}{\lambda^4}$) and Mie scattering ($\propto \frac{1}{\lambda}$) in the atmosphere, which causes greater scattering at the shorter UVB wavelengths compared to the longer UVA wavelengths. For middle latitudes, the proportion of diffuse UV to global UV is often at least 50% (Grant et al, 1997). Intense atmospheric scattering at the shorter UV wavelengths causes UVB radiation to be more prominent in diffuse UV than global UV (Blumthaler, 1993; Parisi and Kimlin, 1999b; Parisi et al, 2001a; Parisi and Turnbull, 2005). Previous research, for example, Parisi et al (2001a) measured the difference between the relative proportions of diffuse UVB and UVA and the percentage diffuse UVB ranged from 23% at noon in spring to 59% at 3 pm in winter and the percentage diffuse UVA ranged from 17% to 31% for the same times. Also, diffuse UVB has been measured on clear sky days and has been shown to range from 48% to 70% for a small solar zenith angle of 15^o and up to 100% for a larger solar zenith angle (SZA) of 75^o

(Grant and Gao, 2003). Although atmospheric scattering is the main cause of the diffuse component, other factors such as the Earth-Sun distance, SZA or time of day (as shown in Figure 2.1), cloud, aerosols, ozone, albedo and latitude influence levels of solar UV radiation and its components as discussed in the following section.

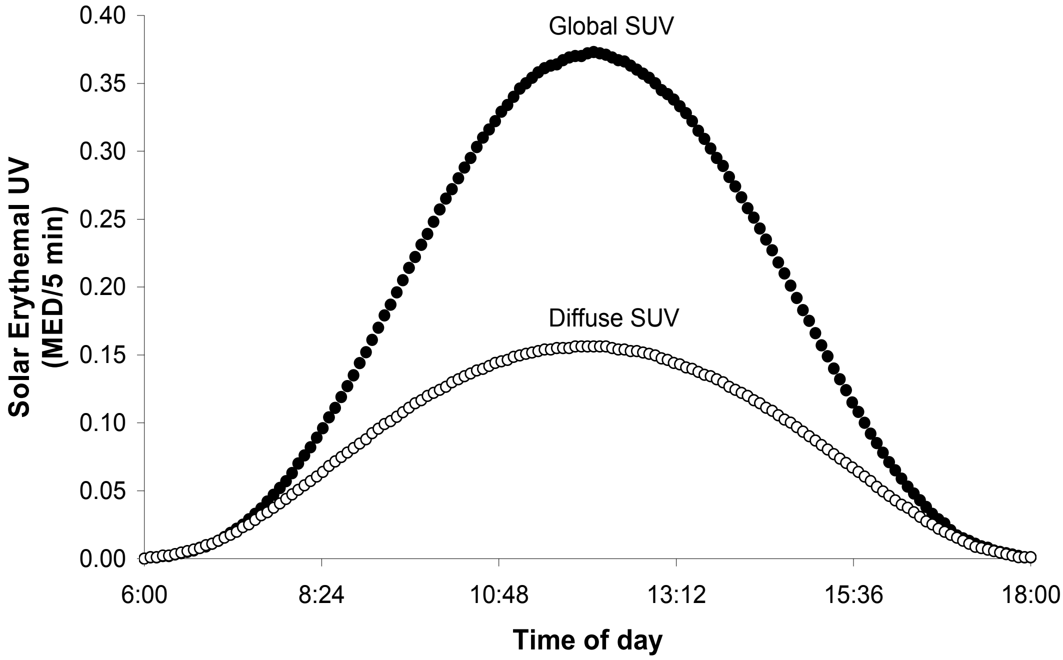


Figure 2.1. Global and diffuse erythemal UV as a function of time of day taken on 8 March 2004.

2.3 Solar UV and the Earth's Atmosphere

Many factors influence solar UV radiation on its path from the Sun, through the atmosphere to the Earth's surface, as it changes from extraterrestrial to terrestrial radiation. Due to the elliptical nature of the Earth's orbit, the distance from the Earth to the Sun varies by approximately 5,000,000 km, with an average distance of 149,597,893 km (Moore, 1995). If the other factors are the same, this variation in distance causes the UV intensities of the Southern Hemisphere summer (perihelion or Earth's closest approach to the Sun) to be slightly more pronounced than the Northern Hemisphere summer (aphelion or Earth's farthest retreat from the Sun).

2.3.1 Solar Zenith Angle

Solar UV radiation depends strongly on the SZA of the sun as it changes with latitude, season and time. The SZA is defined as the angle between the zenith and the sun, or 90^{o} minus the altitude of the sun. In Toowoomba (lat 27.6^{o}S, long 151.9^{o}E; 692 m above sea level), the SZA of the sun in the middle of the day can range from roughly 5^{o} in summer to 53^{o} in winter, as shown in Figure 2.2. For a low SZA predominantly seen during summer, the incident solar UV radiation is more intense because the rays from the sun have a shorter path through the atmosphere and therefore molecular scatterers and absorbers cause less attenuation of the incident radiation. Additionally, the radiation is incident obliquely on a horizontal surface causing the direct component to be spread over a larger surface area. The result of this effect can be seen in Figure 2.3, for spectral UV irradiances taken on 13 August 2004 at 8 am and noon. The shorter wavelength UVB radiation is more effectively attenuated with increasing SZA than are the longer wavelengths associated with UVA radiation. The influence of two SZA for the cut-off wavelength for UVB radiation can also be seen in Figure 2.3. For spectral UV irradiances taken at 8 am and noon, the cut-off wavelength changed from 302 to 295 nm respectively. Diurnal, seasonal and latitudinal variations are more pronounced for UVB radiation (Blumthaler, 1993). The troughs seen in the spectral irradiances are due to Fraunhofer absorption lines. Fraunhofer absorption lines are caused when specific wavelengths are absorbed due to elements in the Sun's atmosphere.

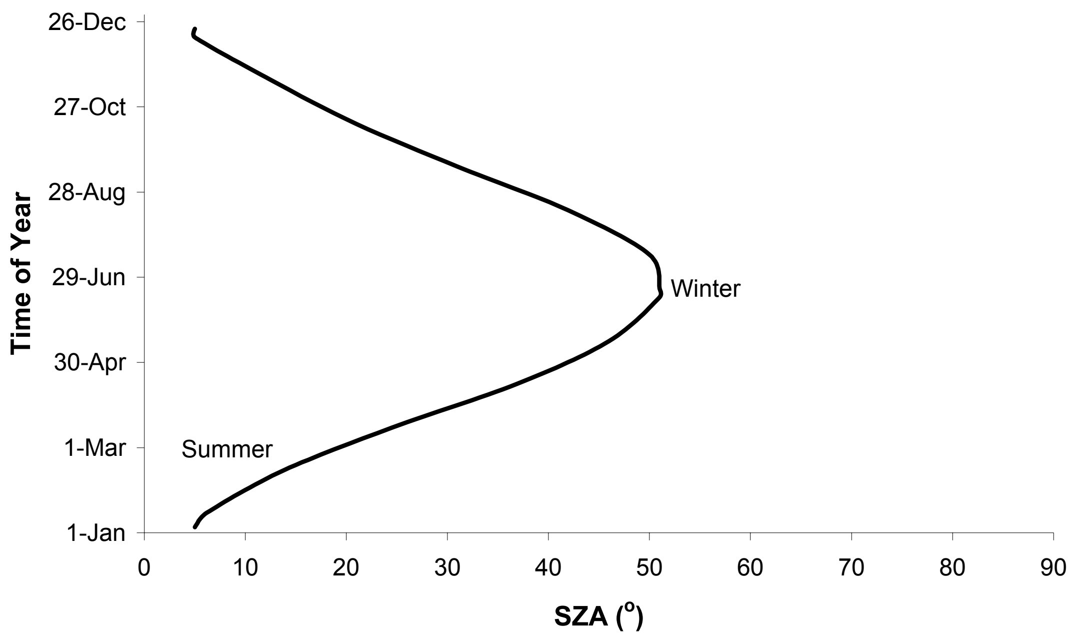


Figure 2.2. Noon SZA as a function of time of year at Toowoomba.

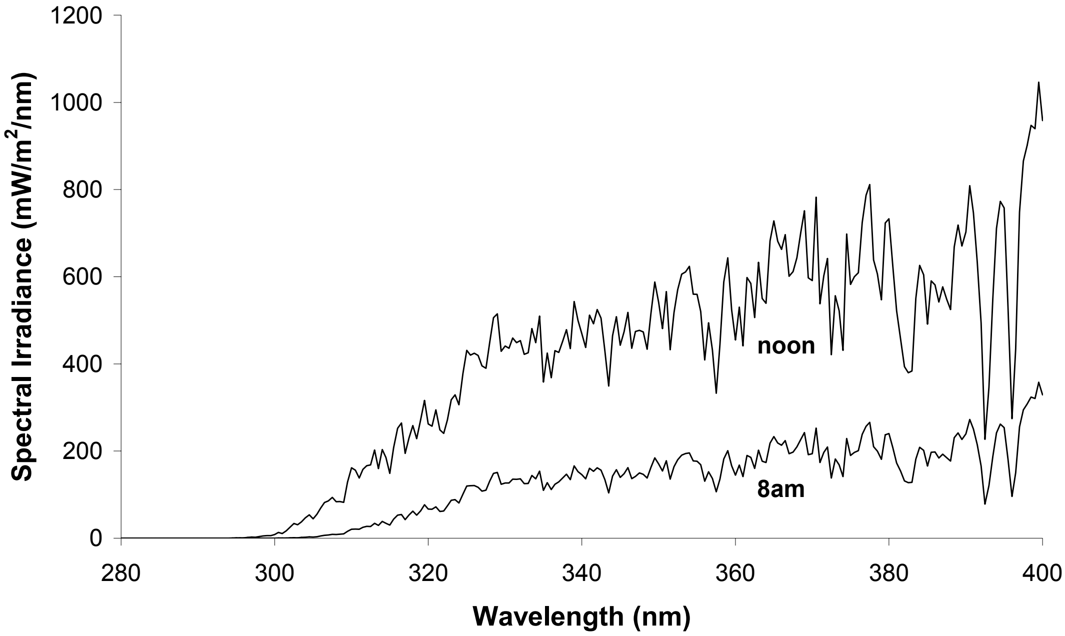


Figure 2.3. Spectral UV for two SZA as a function of wavelength, taken at 8 am and noon, 13 August 2004.

2.3.2 Altitude

The increase in solar UV radiation with altitude is called the altitude effect, and it is referred to as the percentage increase over 1000 m relative to the lowest measurement site (Blumthaler, 1993). The UV irradiance increases with altitude because the amount of absorbers in the overlying atmosphere decreases with altitude. Therefore, the altitude effect depends on SZA due to stronger scattering at the shorter UVB wavelengths. The altitude effect also depends on the turbidity of the atmosphere and albedo of the surrounding terrain (Blumthaler, 1993; Blumthaler et al, 1997; Ambach et al, 1993). For clear sky conditions during summer, observed increases in irradiance with altitude for daily global irradiances have ranged from 8%±2% per 1000 m for total irradiance, 9%±2% per 1000 m for UVA and 18%±2% per 1000 m for the erythemal irradiance (Blumthaler et al, 1997).

2.3.3 Ozone and Aerosols

Life can only exist on Earth because of the protective layers in the atmosphere that are able to stop the deadliest incoming radiation. Absorption by atmospheric oxygen and ozone means that all UVC and most of the UVB incident on the Earth's surface is removed. At the Earth's surface UVA and UVB comprise approximately 8 to 9% of the total incident solar flux (Simon, 1997). UVB constitutes approximately 1.5% of the total incident extraterrestrial solar flux and less than 0.5% of the total incident terrestrial solar flux (Blumthaler, 1993).

The majority of atmospheric ozone is created in the stratosphere (at an altitude of approximately 25 to 50 km) and at this level a large proportion of the UVB is attenuated. UVC is the most energetic and therefore the most destructive of the three wavebands. Solar UVC is not present at the Earth's surface due to attenuation by O_2 molecules in the atmosphere. This attenuation occurs because of the high strength of the O_2 bonds requiring photons in the UVC range to disassociate these molecules into their separate oxygen atoms. These single oxygen atoms are now free to bind to the O_2 molecules and form the ozone molecule, O_3. Incident UVB photons then disassociate the ozone molecules into oxygen molecules, which in turn block the deadly incoming UVC radiation making this a cyclical process.

Ozone concentrations in the stratosphere play an important role in determining the levels of UVB at the Earth's surface. Atmospheric ozone concentration is measured in Dobson units (DU), and 1 DU is defined as 0.01 mm ozone thickness at standard temperature and pressure (STP) (Dobson, 2004). The concentrations are not constant and vary significantly due to a number of reasons, specifically the polar vortices and pollution created by human activity. Some ozone does exist in the troposphere due to production by human activity. While stratospheric ozone is vital for life to survive, tropospheric ozone is a greenhouse gas that affects climate and is a chemical irritant to humans.

The influence of atmospheric ozone on solar UVB radiation increases with decreasing wavelength (Figure 2.4); therefore there is almost no influence of ozone at wavelengths greater than 320 nm (Blumthaler, 1993; Parisi and Kimlin, 1997; Urbach, 1997). Consequently, UVA is mostly unaffected by the atmospheric ozone on its way to the Earth's surface due to its longer wavelengths. The major concern about ozone depletion is the anticipated increase in solar UVB radiation and the ensuing increase in damage to human and other biological systems (Basher et al, 1994). A decrease in atmospheric ozone results in both an increase in the irradiances of the shorter wavelengths and a shift of the short wavelength cut-off to shorter wavelengths. This coincides with the higher effectiveness of the shorter wavelengths for biological damage. For example, the erythema action spectrum is approximately 1000 times more effective at the shorter wavelengths compared to the UVA wavelengths (CIE, 1987).

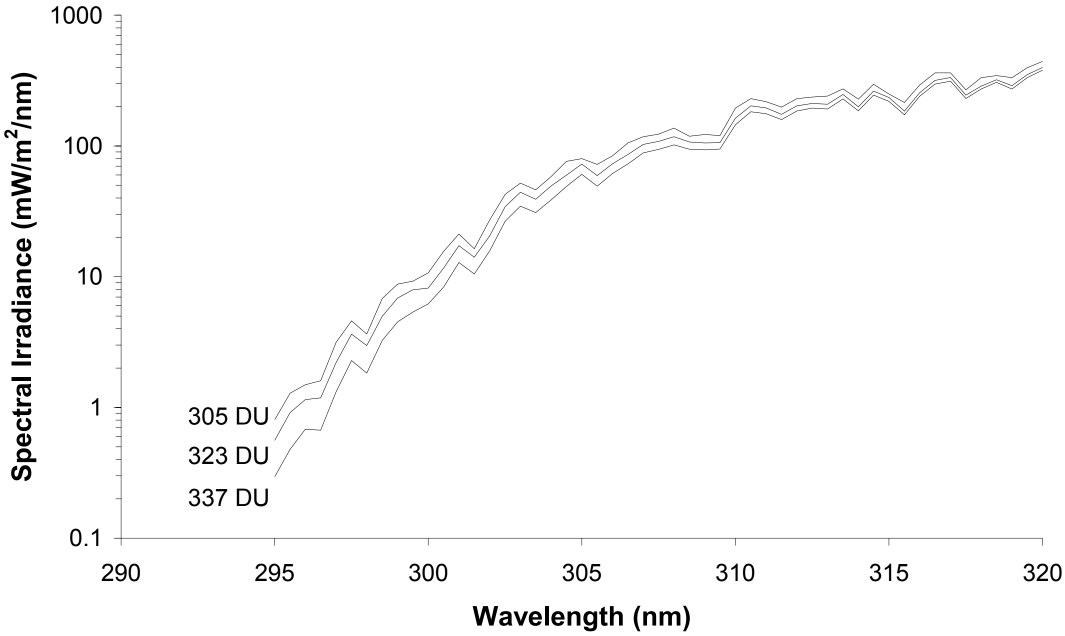


Figure 2.4. Spectral UVB data obtained for a SZA of approximately 33^{o} as a function of wavelength for different ozone levels.

Aerosols are particles of varying size that can be suspended in the atmosphere for differing amounts of time. Aerosols include dust from exposed soil, ocean salts, soot particles from fires, from mining and manufacturing, and from volcanoes (Sturman and Tapper, 1997). The amount of aerosols in the vertical profile of the atmosphere and their size distribution are of significance to the UV waveband (Blumthaler, 1993). The influence of aerosols only slightly depends on wavelength, with a greater effect seen at shorter UVB wavelengths; however, ozone is of more importance with respect to UVB levels (Blumthaler, 1993). Variation in UV irradiance due to changes in aerosol optical depth is considered relatively minor compared to the effects of SZA, cloud and ozone (MacKenzie et al, 1991). The aerosol index is a measure of how much the wavelength dependence of backscattered UV radiation from an atmosphere containing aerosols (Mie scattering, Rayleigh scattering, and absorption) differs from that of a purely Rayleigh scattering atmosphere. The aerosol index is positive for absorbing aerosols and negative for non-absorbing aerosols.

The effect of an ozone variation on the ambient UV radiation is given by a radiation amplification factor, RAF. The RAF represents the percentile change in the annual UV dose per percent change in the density of stratospheric ozone (de Gruijl, 1997). For this research, the RAF (Rsza) is derived by assuming that for each specific SZA, incremental changes in ozone, Z, lead to incremental changes in erythemal UV, E, expressed by the following function (MacKenzie et al, 1991):

$$dE/E = -\mathrm{R}sza\ dZ/Z \qquad (2.1)$$

The RAF is particularly important for evaluating the influence of variations of total atmospheric ozone on biologically effective UV irradiance (Blumthaler et al, 1995). Numerous studies have provided evidence to show that decreases in atmospheric ozone are accompanied with increases in solar UVB flux at the Earth's surface (e.g. McKenzie et al, 1991; McKenzie et al, 1999; Basher et al, 1994; Blumthaler et al, 1995; Kerr & McElroy, 1993; Sabburg et al, 1997). Therefore, if a decrease in ozone concentration is followed by a subsequent increase in solar UVB flux at the Earth's surface, this suggests that there may be an increase in the diffuse erythemal UV associated with a decrease in ozone. This has implications for the solar UV exposures to humans in shade and the effectiveness of other shade minimisation strategies such as hats. However, there has not been a great deal of research on the effect of ozone concentration on the diffuse erythemal UV. The results from this current research will be presented in Chapter 5.

Epidemiological studies (van der Leun and de Gruijl, 1993; de Gruijl and van der Leun, 1993; Kricker et al, 1993) have shown that the incidence of skin cancer among Caucasian populations is elevated for those groups residing in geographical regions that experience higher UV levels. Although, a gradual depletion of atmospheric ozone is not believed to automatically result in a marked increase in the rates of sunburn, because the human skin can adapt to gradual changes in solar UV (de Gruijl, 1997). There is also no reason to suspect that ozone depletion will result in any significant health effects through increased levels of pre-vitamin D_3 (de Gruijl, 1997).

2.3.4 Clouds

For a fixed SZA, UV irradiances are strongly influenced by varying cloud conditions (Blumthaler et al, 1997; Sabburg, 2000; Grant and Gao, 2003; Parisi and Downs, 2004). Clouds generally reduce the UV irradiance, as shown in Figure 2.5, but the attenuation by clouds depends on both the thickness and the type of cloud (optical depth of clouds). Thin or scattered clouds have only a little effect on UV at the ground. Particular configurations of cloud can increase UV levels above that on a cloud-free day (Sabburg and Wong, 2000; Parisi and Downs, 2004). Bais et al (1993) found that overcast skies were capable of attenuating UV in the wavelength range of 290 to 325 nm, by as much as 80%, irrespective of wavelength. Sabburg and Wong (2000) reported that 3% of UVB irradiance measurements (over an entire year) were cloud enhanced. It was also found that 85% of these enhancements occurred for a range of SZA's from 40^o to 63^o. Sabburg et al (2003) reported marginally higher UV enhancements and frequency in the UVB compared to the UVA. Sabburg et al (2003) also found that UV enhancements were wavelength independent for wavelengths longer than 306 nm and increasingly wavelength dependent for shorter wavelengths. Parisi and Downs (2004) also reported that the relative UVA to UVB effectiveness of the action spectra for the biologically damaging process influenced the occurrence of the cloud enhanced UV, with more enhancement occurring for action spectra with a higher relative effectiveness in the UVB waveband.

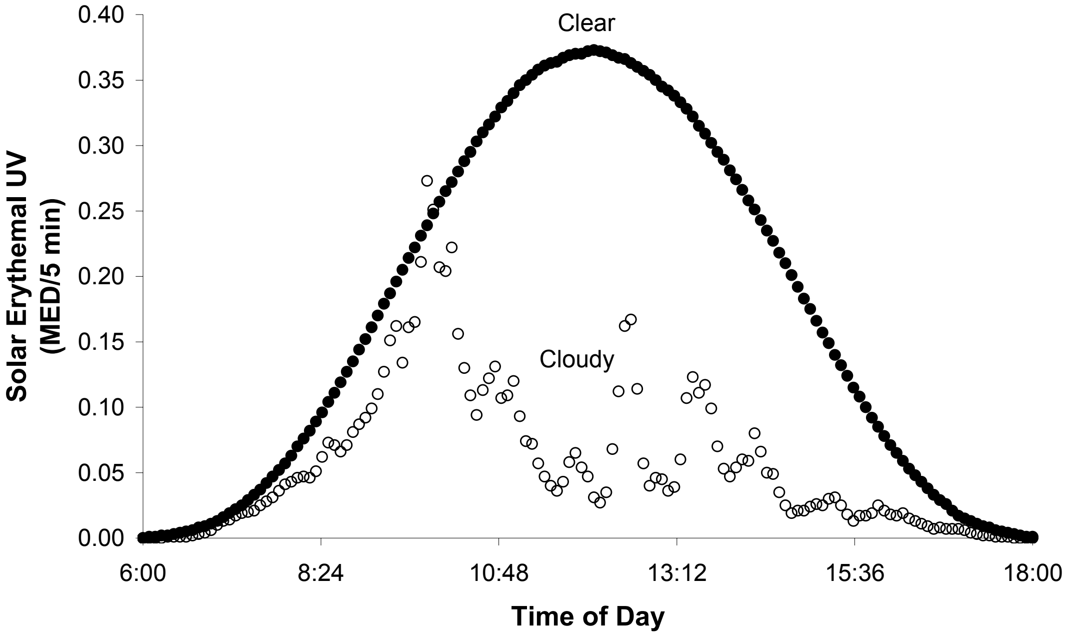


Figure 2.5. Global SUV as a function of time of day for clear sky and cloudy sky conditions.

2.3.5 Albedo

UV radiation that reaches the Earth's surface is absorbed or reflected back to space (Parisi and Turnbull, 2005). The reflective properties (albedo) of the terrain or object significantly influence the level of reflected UV. McKenzie et al (1996) states that the surface albedo of an object is defined as the ratio of the upwelling irradiance to the downwelling irradiance over a horizontal surface. Surfaces such as grass, soil and water reflect less than about 10% of the incident UV radiation (Blumthaler and Ambach, 1988). Sand may reflect up to 25%, whereas the albedo of fresh snow may be up to 80% of the incident UV radiation (Blumthaler and Ambach, 1988). Consequently, anybody over relatively high albedo surfaces will receive higher UV exposures due to the combined effect of the downwelling and upwelling UV radiation. Another major concern with high albedo surfaces is in relation to ocular exposure to UV wavelengths that are effective for producing keratitis, cataract and other sun-related eye disorders. It is generally assumed that the human eyes are usually directed towards the surface and that the ocular exposure results from reflected radiation (Ambach et al, 1993). This is of particular importance to persons working on high albedo surfaces such as metal roofs where the eyes are predominantly directed towards the roofs surface. Roofing materials such as galvanized iron have been shown to reflect as much as 30% of the incident UV radiation (Lester and Parisi, 2002).

2.4 Health Effects of UV Radiation

The biological effects caused by exposure to solar UV radiation are many and varied. Low level exposure to UV radiation can be valuable for the production of vitamin D_3 in the human body, treatment of psoriasis and boosting morale for sufferers of seasonal affective disorder (SAD) (Siegel, 1990). However, the detrimental effects of solar UV radiation far outweigh the beneficial. These harmful effects range from skin cancer, through immune suppression to eye problems (Urbach, 1997; MacKie, 2000; Repacholi, 2000). The biological effects related to solar UV exposure are discussed in the following sub-sections.

2.4.1 UV Radiation and the Human Response

Melanocytes in the human body produce a substance called melanin which regulates the extent to which UV radiation is able to penetrate the human skin, the higher the concentration of melanin the more UV is attenuated (Chedekel and Zeise, 1997) with a strong cut-off wavelength below 300 nm (de Gruijl, 1997). The skin has developed various mechanisms to protect itself from the deleterious effects of UV exposure, a general response of the skin to irradiation by UVB is a thickening by an increase in the number of cell layers called hyperplasia (de Gruijl, 1997; Urbach, 1997). A number of conditions are well accepted as being associated with excess ultraviolet radiation exposure. The more immediate and most common effect on human skin to over exposure of solar UV radiation is erythema (sunburn).

Solar UV is also associated with a number of ocular diseases; the most common is keratoconjunctivitis or snow blindness which is an inflammation of the eyeball (NHMRC, 1996; van der Leun and de Gruijl, 1993; de Gruijl, 1997). Another effect caused by solar UV is cataracts; however, these diseases are most commonly seen in the elderly (van der Leun and de Gruijl, 1993).

UV-induced types of skin cancer include basal cell carcinoma (BCC), squamous cell carcinoma (SCC) and malignant melanoma (MM). Research shows that there is a clear relationship between repeated exposure of the skin to UV and the incidence of BCC and SCC (Hill et al, 1992; Urbach, 1997; MacKie, 2000). Although sunlight exposure is implicated in melanoma development, the relationship with exposure is not completely certain as melanoma is not generally located on highly exposed areas of the body (Setlow et al, 1993; Preston and Stern, 1992; Urbach, 1997). It is thought that intermittent severe exposures (severe enough to cause sunburn) are critical for UV-induced melanoma and that UV exposures in infancy are more dangerous than exposures later in life (Ambach and Blumthaler, 1993; Hill et al, 1992; Stanton et al, 2000). Although melanoma is generally a disease of adulthood, research has shown that children are capable of suffering from this disease (MacLennan et al, 1992).

Analysis of UV exposure data shows that people living in the USA, actually get less than 25% of their lifetime UV dose by the age of 18 (Godar et al, 2003). Similar exposure patterns are also reported for Australia (Parisi et al, 2000b). Solar UV damage early in life can be enhanced by ensuing exposures which progress into tumours later in life, as non-melanoma skin cancer (NMSC) is dependent on the cumulative UV dose (Godar et al, 2003). Therefore, sun protection will have the greatest impact if delivered early in life (Armstrong and Kricker, 2001).

2.4.2 Incidence and Mortality

Levels of incidence of, and mortality 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 (ACCV, 1999). According to the Australian Bureau of

Statistics (2000), 128102 people died in 1999 from various causes: malignant neoplasms (cancer) accounted for 27% of these registered deaths, and skin cancer kills more than 1000 people each year. Skin cancers of all types are primarily a problem for those of European descent (ACCV, 1999) and have dominated cancer incidence in Australia, where they outnumber all other forms of cancer at least two to one (Giles et al, 1988). The incidence rates for NMSC in Australia in 1995 were estimated at 788 per 100000 for BCC and 321 per 100000 for SCC; MM showed a much lower rate of 30 per 100000 in 1993 (Sinclair et al, 2000; Staples et al, 1998). The incidence rate of each type of skin cancer is higher in fairer skinned populations rather than darker skinned (Armstrong and Kricker, 2001). Incidence rates of MM in white populations in the United States for 2001 were estimated at 14.4 per 100000 for women and 21.5 per 100000 for men (CDC, 2004). Although melanoma is generally a disease of adulthood, research has shown that children in Queensland, Australia, had the highest incidence rates of melanoma in the world (MacLennan et al, 1992). By 1997, melanoma was rated as the fourth most common cause of death due to cancer, after prostate, colon and lung cancer in men, and cancer of the breast and colon in women (CCA, 2001; NHMRC, 1996). NMSC is by far the most frequently occurring malignancy and therefore represents an important health care problem (Fears et al, 1976).

2.5 Biologically Damaging UV Radiation

In order to estimate the biological sensitivity of an organism to UV radiation the wavelength dependence of the damaging radiation must be calculated (Young et al, 1993).

2.5.1 Action Spectra

Action spectra are used to show the relation between the irradiating wavelengths and the effect on certain biological processes (Jagger, 1967). Monochromatic action spectra are the most common way of representing the wavelength dependence of biological effects, and are obtained in laboratory studies by exposing biological targets to various isolated wavelengths of radiation and comparing the responses (ed Young et al, 1993). For ethical reasons it is not possible to determine the wavelength dependence of biologically damaging UV directly in humans, therefore an action spectrum is directly determined from animal experiments (de Gruijl, 1997) as in the case of the melanoma and cataract action spectra. The interfering effect of ultraviolet radiation on a specific biological process is wavelength dependent and therefore the UV spectrum must be weighted with the appropriate action spectra for the respective processes (Wong & Parisi, 1999). Action spectra provide only a relative biological response; they do not give the absolute biological effect (Madronich, 1993).

Coohill (1991) states that combining a specific action spectrum with the known amount of UV radiation reaching the biosphere can give rise to estimates of the exposure rates and subsequently the effects of solar UV. Given the spectral irradiance, $S(\lambda)$, and an action spectrum, $A(\lambda)$, for a particular biological effect, the product of the two $S(\lambda)\ A(\lambda)$ defines the spectral irradiance with the units $Wm^{-2}nm^{-1}$. Integration of the effective spectral irradiance across a desired wavelength range ($\lambda 1$ to $\lambda 2$) gives the effective irradiance:

$$\text{Effective irradiance} = \int_{\lambda 1}^{\lambda 2} S(\lambda)\, A(\lambda)\, d\lambda \;\; (\mathrm{Wm}^{-2}) \qquad (2.3)$$

This gives a measure of the biologically effective irradiance at any given instant. The exposure over a given time period can be calculated by integrating equation 2.3 with respect to time, t, for an exposure period from t1 to t2.

$$\text{Effective exposure} = \int_{t1}^{t2} \int_{\lambda 1}^{\lambda 2} S(\lambda)\, A(\lambda)\, d\lambda\, dt \;\; (\mathrm{Jm}^{-2}) \qquad (2.4)$$

Irradiances and exposures for different biological effects cannot be numerically compared with each other due to the normalization of the respective action spectra (Madronich, 1993).

Action spectra are quite diverse and are available for the detrimental skin disorders (Figure 2.6) and ocular disorders (Figure 2.7) to the beneficial effects of pre-vitamin D_3 synthesis (Figure 2.8). The types of action spectra include spectra for such things as erythemal damage (CIE, 1987), actinic damage (IRPA/INIRC, 1989), fish melanoma (Setlow et al, 1993), DNA damage (Caldwell et al, 1983), porcine cataract (Oriowo, 2001), photoconjunctivitis (CIE, 1986a) photokeratitis (CIE, 1986b), and pre-vitamin D_3 synthesis (Webb et al, 1988).

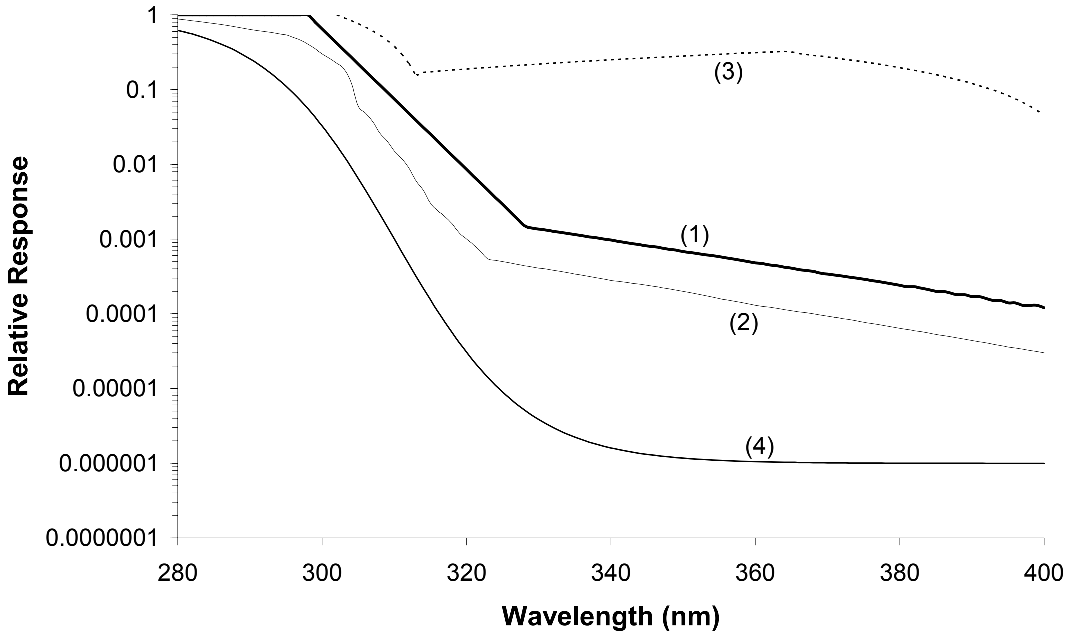


Figure 2.6. Action spectra for erythema (1), actinic (2), fish melanoma (3), and DNA damage (4).

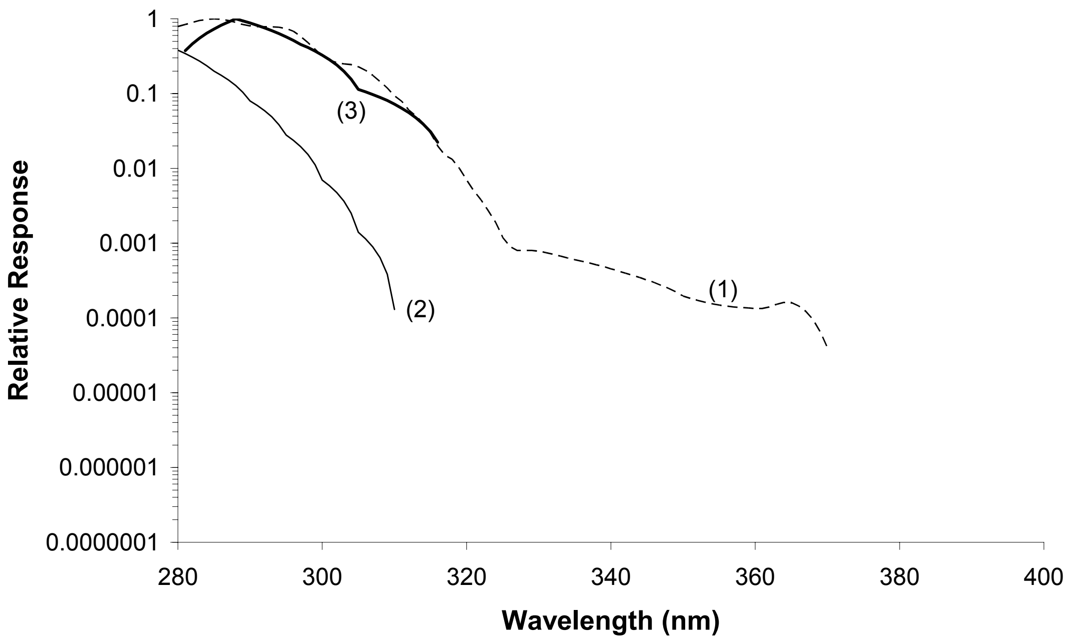


Figure 2.7. Action spectra for porcine cataracts (1), photoconjunctivitis (2) and photokeratitis (3).

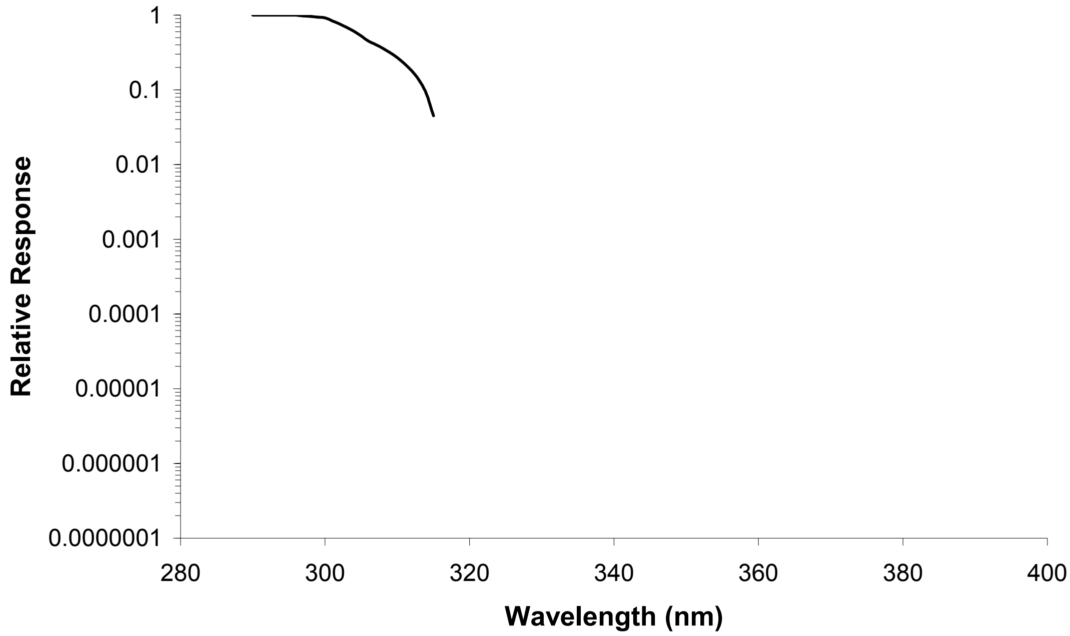


Figure 2.8. Action spectrum for pre-vitamin D_3 synthesis.

The erythemal action spectrum is of primary concern with the work conducted in this project as erythema is thought to be a precursor to skin cancer (Setlow, 1974; Urbach, 1997). Erythema is defined as the reddening of the skin after exposure to solar UV radiation. As shown in Figure 2.6, the UVB wavelengths are the most biologically effective at producing erythema. For example, UV wavelengths at 298 nm are 1000 times more biologically effective than those at 339 nm with respect to erythemal damage. It is necessary to note that skin type plays a major role in the effectiveness of solar UV radiation to produce erythema (Table 2.1).

Table 2.1. Reaction of various skin types to solar UV radiation exposure (Diffey, 1991).

Skin Types and Reactions to UV Radiation		
Skin Type	Description	Skin Reaction
1	Fair skin, blue or green eyes, freckles, white skin	Burns severely and easily, peels, little or no tan
2	Fair skin, blue eyes, blond or brown hair, white skin	Burns severely and easily, peels, tans minimally
3	White skin, black or brown hair, brown eyes (average Caucasian)	Burns moderately, tans gradually
4	White, olive or light brown skin, dark brown hair and dark eyes (Mediterraneans, Orientals)	Seldom burns, tans easily
5	Dark brown skin (often Asian or Indian descent)	Almost never burns, tans substantially
6	Black or dark brown skin, hair and eyes (African-Americans, Aborigines)	Never burns, tans profusely

2.6 Chapter Discussion

Australia has the reputation as having one of the highest rates of incidence and mortality for skin cancer in the world. It has long been established that over exposure to solar UV radiation is linked with the development of skin cancer and ocular disorders. Personal UV exposure is due to sunlight received as both direct and diffuse UV radiation. There are a number of factors that affect UV radiation levels at the Earth's surface, and the most important of these have been discussed in this chapter. This current project is concerned with erythemal UV radiation. The most important wavelengths associated with erythemal UV exposure are found in the UVB waveband. This is important because there is a significant increase in the relative amounts of atmospheric scattering at these shorter wavelengths. Therefore, understanding the diffuse erythemal UV environment forms a significant part of this research.

CHAPTER 3

SOLAR UV RADIATION IN THE SHADE

3.1 Introduction

As the population's understanding in relation to the damaging effects of UV radiation increases, shaded environments will be sought to reduce damaging UV exposure levels (Moise and Aynsley, 1999; Turnbull and Parisi, 2003). It is not often appreciated that people sheltering under trees or shade structures are exposed to a considerable amount of scattered UV radiation (Parsons et al, 1998; Turnbull and Parisi, 2003; Turnbull et al, 2003). A common misconception is that shade protects the human body against all ultraviolet radiation. While direct UV from the Sun is generally reflected or absorbed by the shade structure, the diffuse component is still present in the shade. Atmospheric scattering and scattering by the environment are the main causes of the diffuse UV, although other factors impact on the amount of UV radiation that exists in the shade. Over exposure to this diffuse radiation may cause a number of short term and long term conditions, for example erythema and photokeratitis. While there are numerous guidelines for the design of various shade environments (e.g. DAUQ, 1995; 1996; 1997; 1999; AIEH, 1995), most forms of shade still offer people insufficient protection from UV radiation (Turnbull and Parisi, 2003; Turnbull et al, 2003). Therefore, a need exists for more detailed research on the interaction of UV radiation with shade environments and subsequent ways to reduce personal UV exposure in the shade.

3.2 UV Radiation in the Shade

Local governments provide many and various shaded environments for public use. These structures include gazebos, vegetation, shade cloth, polycarbonate sheeting and various opaque building materials (Toomey et al, 1995). Numerous quantitative studies concerning the effects of solar UV beneath various forms of shade have been conducted over many years (e.g. Grant and Heisler, 1996 and 1999; Grant et al, 2000 and 2002; Moise and Aynsley, 1999; Wong, 1994; Parsons et al, 1998; Parisi et al, 1999; Parisi et al, 2000a; Parisi et al, 2000b; Parisi et al, 2000c; Parisi et al, 2001b; Parisi et al, 2001c; Parisi et al, 2001d; Parisi et al, 2003; Turnbull et al, 2003; Turnbull and Parisi, 2003). Parisi et al (2000c) found that over a summer period approximately 60% of the erythemal UV was due to the diffuse component, and that different shade environments provide different amounts of protection. Moise and Aynsley (1999) measured the UV beneath eight different shade environments and found that only one (dense foliage) had a UVB sun protection ratio equal to or higher than 15. Many studies have investigated the protective ability of trees (for example, Parsons et al, 1998; Parisi et al, 2000c; Parisi et al, 2001b; Grant et al, 2002; Parisi et al, 2003) and have found that tree shade does not offer adequate UV protection. Toomey et al (1995) studied shade cloths and polycarbonates, and found that canvas materials offered the greatest protection, while horticultural cloths transmitted up to 50% of the incident UV radiation. Turnbull and Parisi (2003) measured the UV spectrum underneath four different public shade structures during autumn and winter and found that biologically damaging UV radiation present in the shade ranged from 14% for a covered verandah up to 84% for a shade umbrella. Gies and MacKay (2004) found that only six of twenty-nine shade structures in New Zealand primary schools offered a UV protection factor greater than 15, which is required to provide sufficient all-day protection. The research presented in this project extends previous research by concurrently measuring the diffuse UV on a horizontal plane in full sun and the angular distribution of UV in the shade of three public shade structures for the broad range of solar zenith angles seen throughout the year. Also, the research presented in this thesis will show how scattered UV levels in the shade are influenced by side-on protection for a range of solar zenith angles.

3.3 Solar Radiation and Thermal Comfort

Many people associate shading with a reduction in UV radiation because their skin feels cooler and the reduction of the visible wavelengths. The perception of a decrease in temperature and visible radiation is not generally indicative of UV levels, as scattered UV can still reach the shaded skin and eyes (Trouton and Mills, 1997; Moise and Aynsley, 1999; Turnbull and Parisi, 2003). The human eye detects radiation at wavelengths that range from approximately 380 to 780 nm with a peak response at 555 nm (CIE, 1990) (Figure 3.1), whereas the human skin detects the longer wavelength infrared radiation. However, there is no immediate physical means by which the skin and eyes detect UV, apart from the delayed reactions of damage to the skin and eyes, including erythema. While UV and visible radiation in full sun are dependent on SZA (see Figures 2.5 and 3.2), research by Turnbull and Parisi (2003) showed that while scattered UV in the shade did show a dependence on SZA, visible radiation in the shade showed no such dependence. The implications of this are that UV damage can still be done to the skin and eyes even though the thermal and visible environment may be significantly reduced.

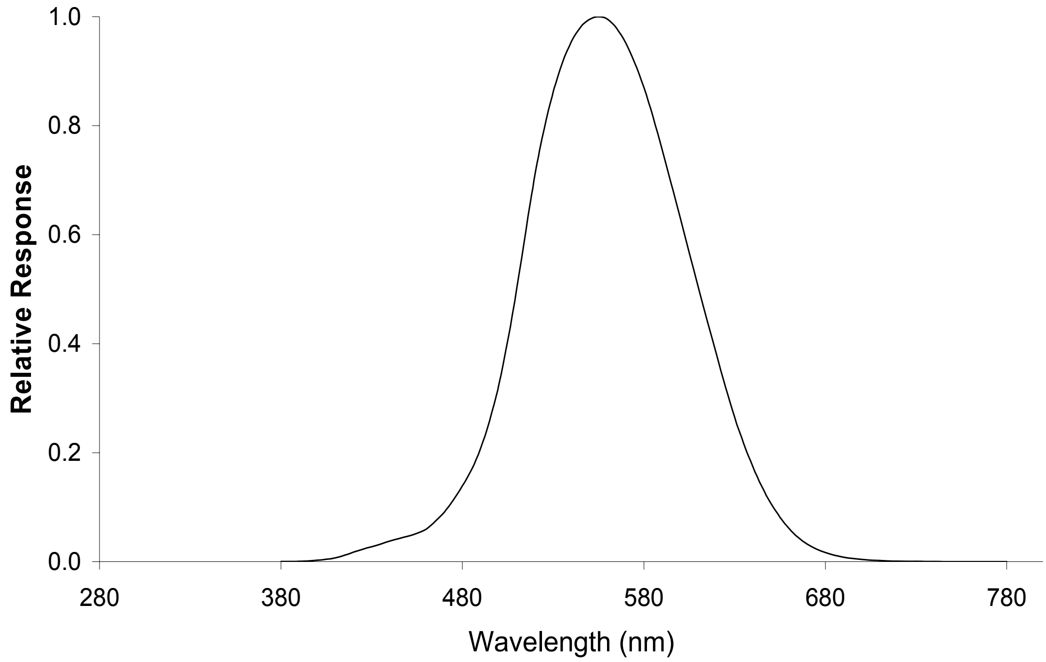


Figure 3.1. Human eye sensitivity as a function of wavelength (CIE, 1990).

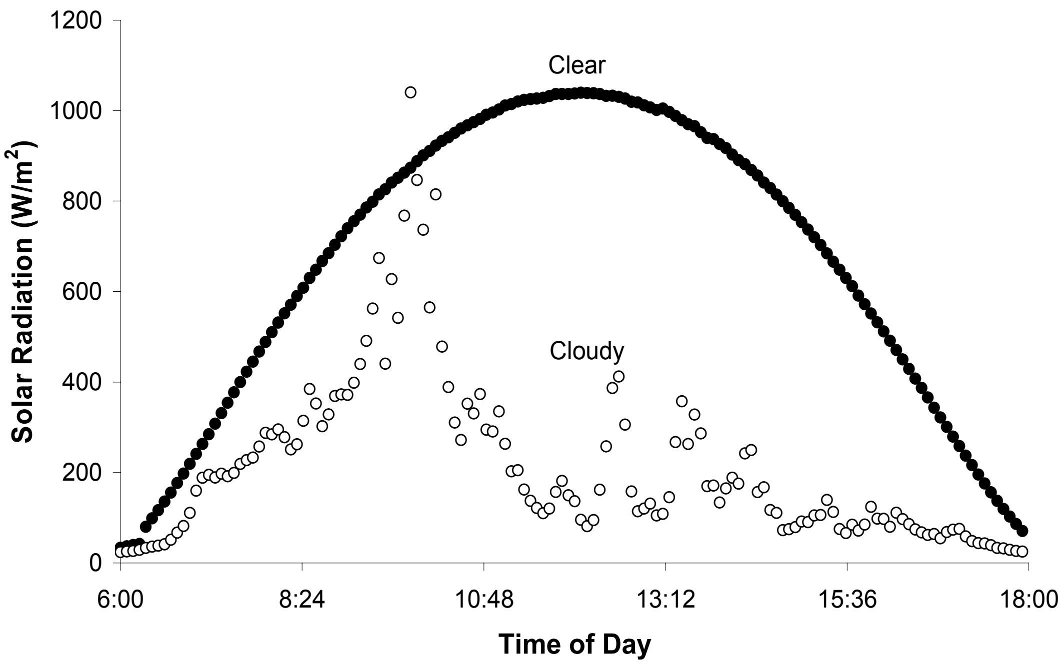


Figure 3.2. Solar radiation (400 to 950 nm) as a function of time of day for clear sky and cloudy sky conditions.

Subjective comfort is a determining factor for personal UV exposure, with people exposing more and more skin as they become hotter due to rising temperature levels (Hill et al, 1992). When the outside temperatures reach extreme levels, people will stay out of the sun because of discomfort (Turnbull and Parisi, 2003). Consequently, solar radiation from the sun that human skin perceives as heat is in the far-infrared region of the electromagnetic spectrum which is on the opposite side of the visible waveband to UV radiation.

People will generally seek shade in summer because it is hot, but in winter people will seek places that are warm. MacKay and Donn (2002) found that school students preferred light and warm shade that was large enough to group within. 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 (Greenwood, 2002). Visible light intensity also does not give an indication of UV levels in the shade (Turnbull and Parisi, 2003).

3.4 Shade Policy and Guidelines

Cancer control in Australia is one of the National Health Priority Areas and it is recognised that while it may not be possible to eliminate cancer altogether, its impact and burden on the community can be significantly reduced (CCNSW, 2001). The reduction of global and diffuse UV radiation is of enormous importance with respect to personal UV exposure and shade. Environments that do not provide sufficient shade place great demands on individuals to protect themselves in the sun (DHFS, 1998).

One of the effective interventions identified in the National Cancer Prevention Policy (NCPP) 2004-06, is to provide sun-protective conditions for all (CCA, 2004). The NCPP 2004-06 states that: “Interventions that improve sun-protection conditions for all people in a defined population (childcare centre, school, sporting group, life-saving service and workplace, and community settings such as sports grounds, parks and outdoor entertainment areas), not just for those who are most motivated. Strategies include increasing shade, supplying sunscreen, and adopting policy, guidelines and legislation that involve formal rules or standards, legal requirements or restrictions relating to skin cancer protection measures”. Of the aims acknowledged in the NCPP 2004-06 for the reduction of personal UV exposure, a number of them are directed at achieving policies and practices that promote sun protection. One goal of the NCPP 2004-06 is to increase the amount of natural or constructed shade in public places by way of developing and disseminating appropriate guidelines and policies to relevant groups (CCA, 2004). This intervention is also one of the four key strategy areas outlined in the Queensland Skin Cancer Prevention Strategic Plan 2001-2005, which is to extend access to and promotion of the use of shade areas (QHP, 2001).

Numerous guidelines on the construction of shade environments for varying situations from schools to swimming pools to sports fields have been developed (e.g. DAUQ, 1995; DAUQ, 1996; DAUQ, 1997; DAUQ, 1999; AIEH, 1995; Greenwood et al, 2000). However, of primary concern with these guidelines is that they are not based on adequate levels of quantitative research into UV radiation and its interaction with different shade environments under different conditions. A number of these guidelines reinforce the point that the design and construction of shade structures requires considerable technical expertise (NSWHD, 2001). Also, these guidelines are now out of date, as new and more extensive research has recently been conducted quantifying UV in the shade of different shade environments (for example, Turnbull and Parisi, 2003; Turnbull et al, 2003; Turnbull and Parisi, 2004; Turnbull and Parisi, 2005; Parisi, 1999; Parisi, 2002; Parisi et al, 1999; Parisi et al, 2000a; Parisi et al, 2000b; Parisi et al, 2000c; Parisi et al, 2000d; Parisi et al, 2001a; Parisi et al, 2001b; Parisi et al, 2001c; Grant, 1997a; Grant, 1997b; Grant and Heisler, 1996; Grant and Heisler, 1999; Grant et al, 2000; Grant et al, 2002; Moise and Aynsley, 1999; Gies and MacKay, 2004). Another concerning factor is that the guidelines seem to be based more on the aesthetic appeal of the actual structures being the number one priority rather than providing the most effective shade possible.

Past research into different shade environments has been reviewed in Section 3.2 and has shown that very few shade environments are effective at significantly reducing UV exposure. Personal UV exposure is caused by exposure to both direct and diffuse UV radiation. While the direct component is easy to negate by simply blocking its path, the diffuse component is incident from all directions and difficult to minimize with the usage of hats, tree shade and shade structures.

3.5 Chapter Discussion

The question about shade structures now is: what makes an effective shade structure? According to Parsons et al (1998), effective shade should offer a UV protection ratio greater than 15 (93% reduction in UV). Turnbull and Parisi (2002a; 2002b; 2003) state that shade should offer maximum protection for a changing SZA, as the shade may not necessarily always be beneath the actual shade structure (Turnbull et al, 2003). At high SZA's it may be outside the structure causing personal UV exposure to be increased. Research into UV exposure beneath shade structures during winter by Turnbull et al (2003) showed that UV levels in the shade at a sub-tropical site were still high enough to cause damage. Therefore, shade structures should also offer adequate thermal comfort for different weather conditions and seasons. Otherwise, winter shade will not be utilized when needed due to the temperature in the shade being too cold.

The research conducted in this project is aimed at understanding the global and diffuse UV within the shade created by specific public shade structures. Furthermore, modifications will be made to one type of structure in order to significantly reduce the personal UV exposure beneath this shade structure. The research presented in this thesis will address one of the goals set out in the NCPP 2004-06, which is to increase the knowledge on the construction of appropriate shade in public places.

CHAPTER 4

SOLAR RADIATION MEASUREMENT

4.1 Introduction

The measurement of solar UV radiation is a necessary and multifaceted undertaking, and is done to gain a better understanding of how solar UV affects different terrestrial environments. Spectroradiometers, broadband meters and dosimeters are often utilised for the measurement of incident solar UV radiation. Of these devices, the spectroradiometer is the most versatile as it allows the determination of the intensity of the radiation from a source as a function of its wavelength (Webb et al, 1994; Gibson and Diffey, 1989). Broadband meters, on the other hand, report the total energy received across a given waveband, which is often weighted with an approximate biological action spectrum (Webb et al, 1994). Detailed information of the spectrum of incident solar radiation provided by a spectroradiometer has greater versatility than a single broadband measure (Webb et al, 1994). However, the broadband instruments are cheaper and easier to use. Another alternative means of measuring UV irradiance is by the use of dosimeters. Dosimetry involves exposing a substance to solar UV radiation and then measuring the photochemical or photobiological changes.

The data measurement site for this research was the campus of the University of Southern Queensland (USQ), Toowoomba, Australia (27.6^{o}S, 151.9^{o}E, altitude 692 m a.s.l.). This sub-tropical site of Toowoomba has the properties of having low levels of atmospheric pollutants and a high number of clear sky days as well as being located at the southern most point of the Southern Hadley Atmospheric circulation cell (Sabburg et al, 1997). The physical location of Toowoomba is on a plateau of the Great Dividing Range with the surrounding country being typically agriculture. Toowoomba is one of Australia's largest inland cities with very little heavy industry. The following sections of this chapter will detail the instruments, materials and the method of use for the research conducted in this project.

4.2 Measurement Devices

4.2.1 Radiometry

4.2.1.1 Broadband Radiometers

Two permanently mounted outdoor erythemal UV meters (UV-Biometer Model 501 Version 3, Solar Light Co., Philadelphia, PA) (Figure 4.1) were employed during this research to monitor the global and diffuse SUV. The global and diffuse broadband meters are based on the Robertson-Berger meter and consist of a diffuser, a filter and a detector. The solar radiation passes through the input filters, eliminating the visible component, and then excites a phosphor element which then emits visible radiation (Solar Light, 1991). This visible radiation is detected by a GaAs diode and is then converted to a readable output. The spectral response of the meter is similar to that of the erythemal action spectrum as shown in Figure 4.1. The angular response of the detectors is described by the manufacturer as within 5% from ideal cosine for incident angles (Solar Light, 1991). The cosine error of the biometers is significantly reduced for the larger SZA by calibrating them against the spectroradiometer described in section 4.2.1.5.

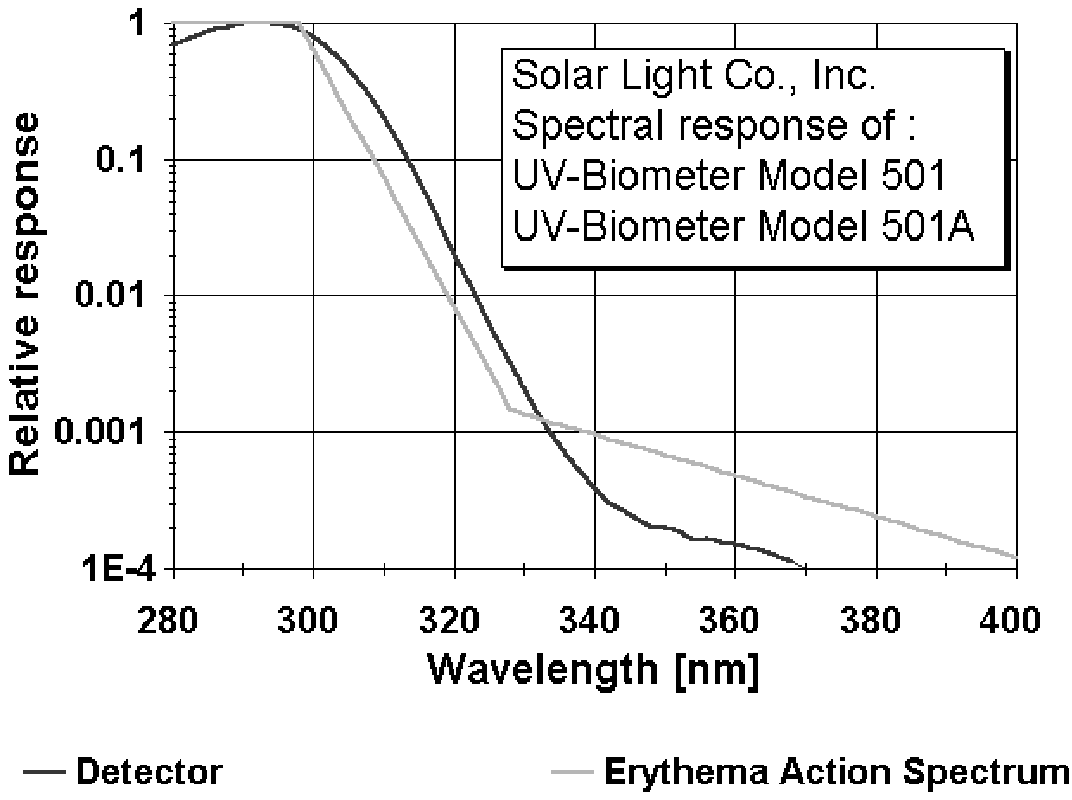


Figure 4.1. Spectral response of the SUV detector (Solar, 2004).

The diffuse SUV meter used in this research is a global SUV meter that has been modified to make use of a specially designed shadow band to block the sun during the day (as described in section 4.2.1.2). The data loggers attached to the meters are set up to record data every five minutes. The meters are temperature stabilized to 25^{o}C and calibrated twice a year during clear sky conditions and a changing SZA against a scanning spectroradiometer for a range of SZA from 49^{o} to 17^{o} in summer and 76^{o} to 50^{o} in winter. These are the solar zenith angles encountered from approximately 8am to noon for summer and then winter respectively. The erythemal action spectrum was used for the calibration of the meters. Table 4.1 provides the calibration factors for the conversion of one MED output by the meter to J/m^2. Calibration charts are provided in Appendix A.

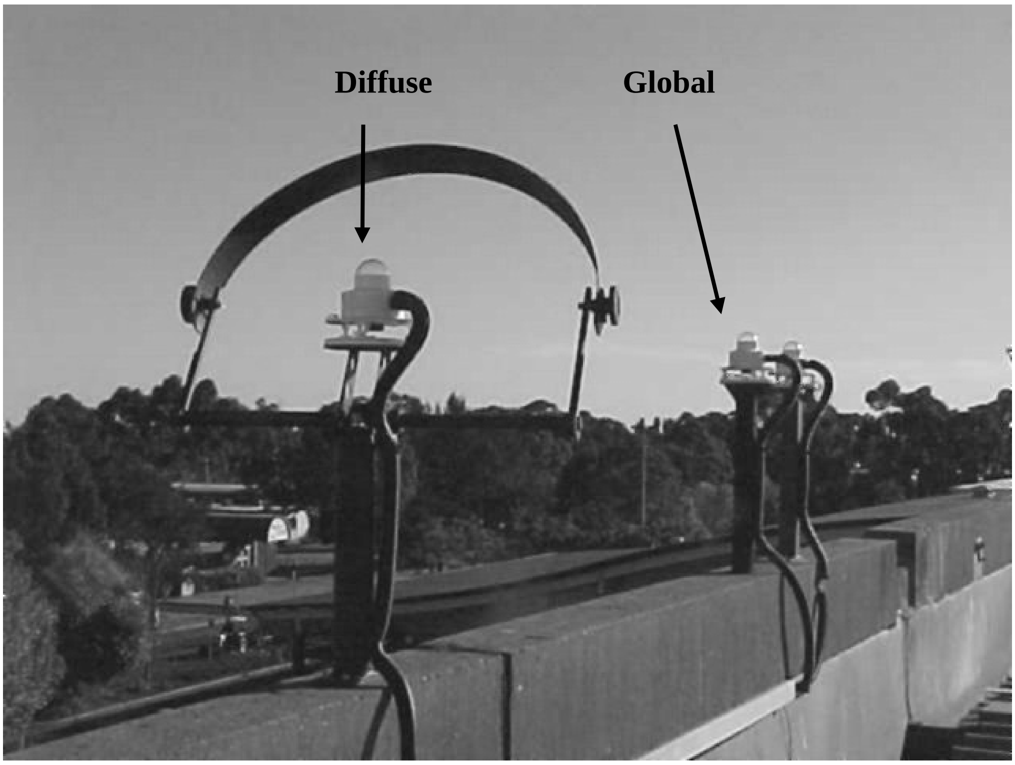


Figure 4.2. Diffuse and global SUV meters.

4.2.1.2 Diffuse Shadow band

The diffuse SUV meter utilizes a shadow band, which was designed during this project, to block the sun as it traverses across the sky during the day. Details of the shadow band are as follows:

- Shadow band (Figures 4.2 and 4.3): The shadow band is 0.076 m wide and 1.12 m long and it is a constant 0.305 m from the eastern and western sides of the quartz dome of the biometer. The band is made from aluminium and is painted black to reduce its reflectivity. The distance from the shadow band to the top of the quartz dome varies from 0.25 m to 0.27 m as it is moved with the seasons. The occluded arc angle of the shadowband is approximately 0.21 radians.

The shadow band articulates at two separate points (Figure 4.3) allowing the sun to be blocked for all times of the day and for all seasons throughout the year. The axes through the points of articulation on the shadow band are set perpendicular to the direction of true north. The SZA and azimuth of the sun for different times of day and year can be taken into account by moving the shadow band at the two articulation points. Once the appropriate SZA and azimuth are determined, the two pieces of equipment shown in Figure 4.4 are placed on top of the biometer and on the side of the shadow band to align it correctly. Movement of the shadow band varies according to time of year, as can be seen in Figure 2.2, where the sun's SZA for noon changes more rapidly during autumn and spring than for summer and winter. Therefore, movement of the shadow can occur bi-weekly during autumn and spring. The shadow band blocks out part of the sky view and this has been measured at approximately 10%. This was done by comparing the diffuse and global SUV for completely overcast conditions (cloud fraction of 1.0) for an entire year (Figure 4.5). A uniform sky radiance was assumed and a subsequent correction factor for this affect has been applied to all of the data to account for this.

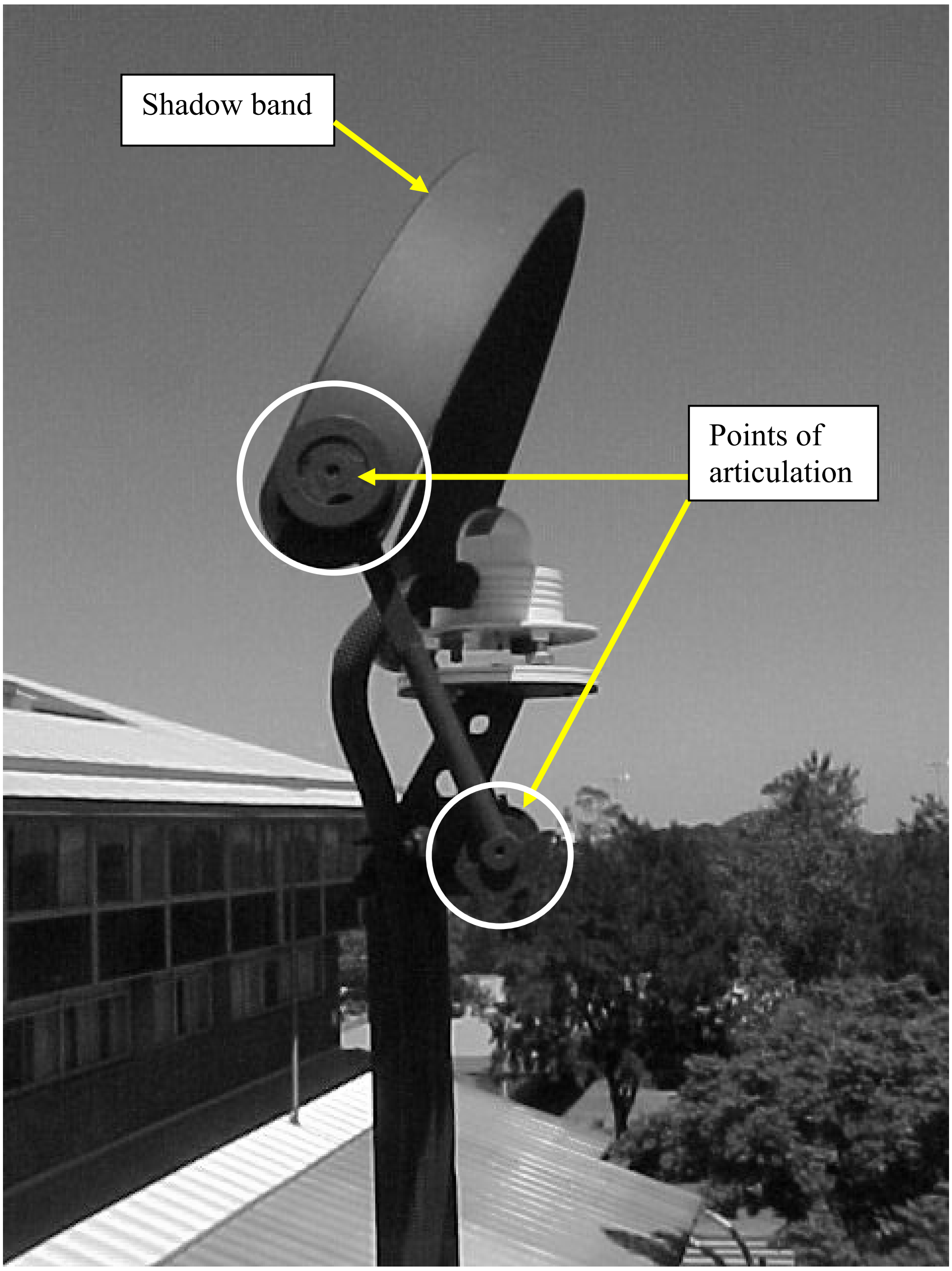


Figure 4.3. Shadow band and SUV meter that comprise the diffuse SUV meter.

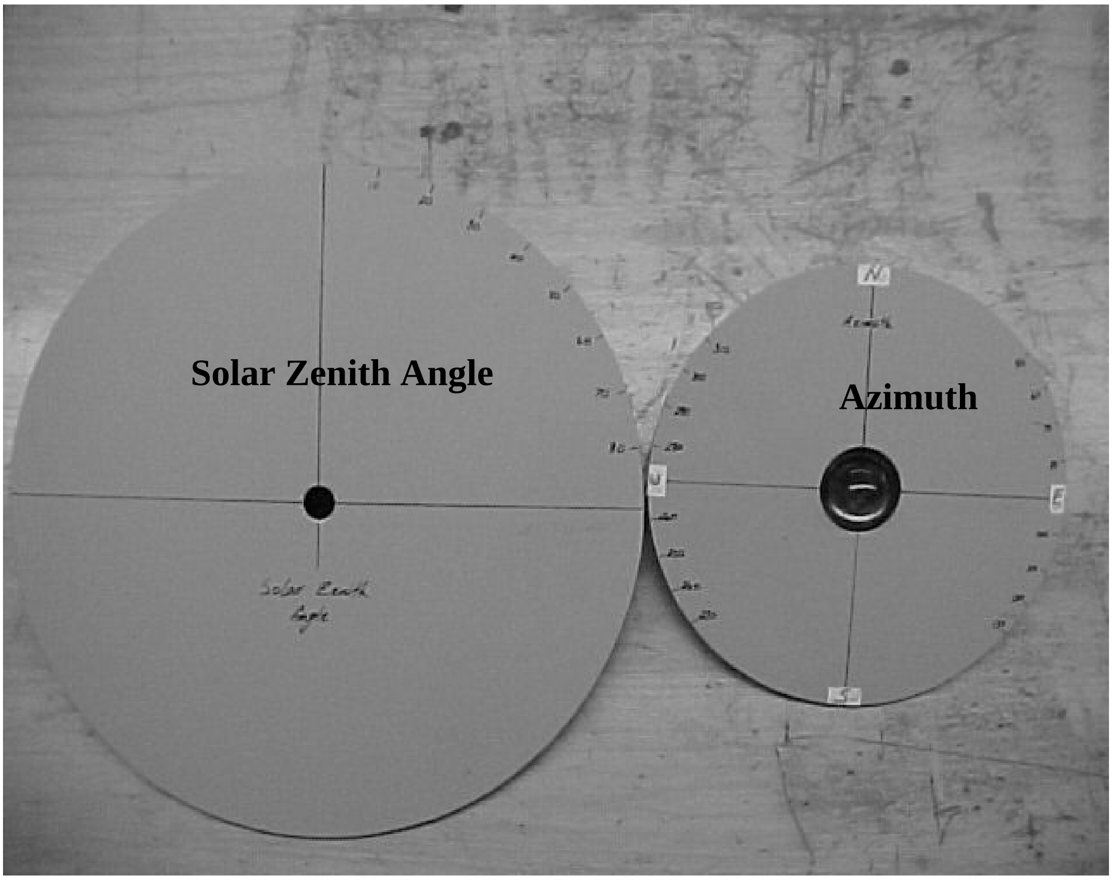


Figure 4.4. Equipment used to align shadow band.

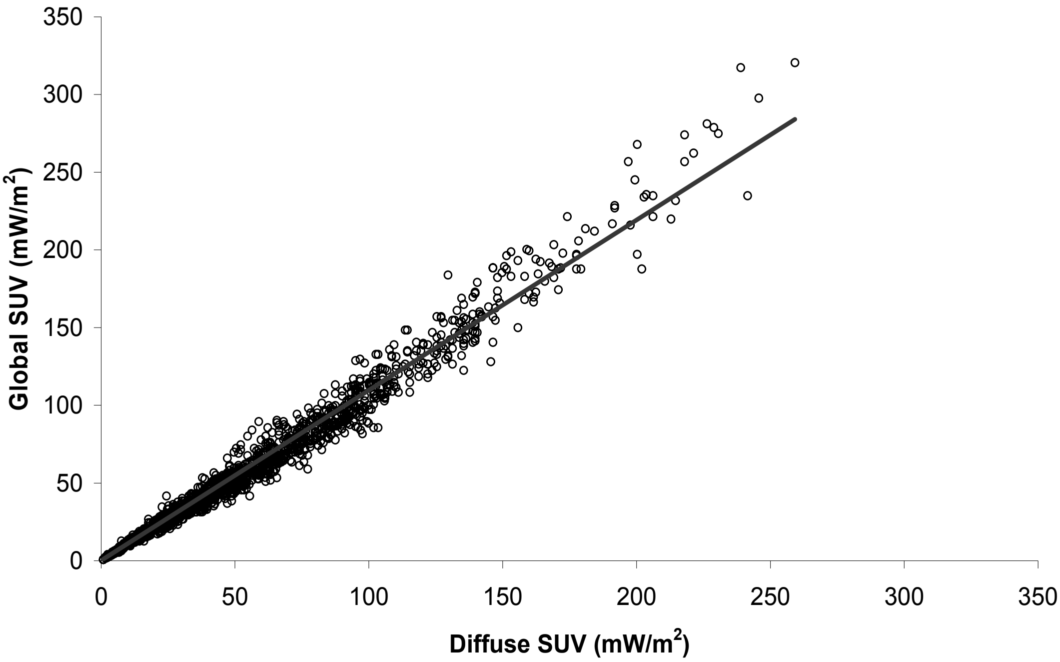


Figure 4.5. Global SUV as a function of diffuse SUV for overcast conditions (cloud fraction of 1.0) for calculation of the shadow band correction.

Table 4.1. Seasonal calibration of the global and diffuse SUV broadband meters.

	Global SUV (J/m^2)	Diffuse SUV (J/m^2)
Winter 02	202.2	204.6
Summer 02/03	235.6	229.5
Winter 03	268.1	269.7
Summer 03/04	298.9	277.0
Winter 04	258.2	265.0

4.2.1.3 Robertson-Berger Meter

For measurements in the field, a hand held Robertson-Berger (RB) meter (model 3D V2.0, Solar Light Co., Philadelphia, PA, USA) fitted with a UVA detector and an erythemal weighted UV detector was used to measure the UV irradiances (Figure 4.6). The spectral response of each detector is shown in Figure 4.7. The cosine response of both detectors is stated by the manufacturer as ±5% for SZA of 0^o to

60°. The RB meter was calibrated against a scanning spectroradiometer for clear skies and a changing SZA of 16° to 66°. The UVA waveband of 320 to 400 nm was used for the calibration. A temperature correction was not needed due to the instrument not being used in a manner that would cause its temperature to fluctuate significantly. Subsequent calibration factors of 0.0297 and 11.034 were calculated and used to convert the output of the SUV and UVA sensors to J/m^2 respectively. The RB meter was kept horizontal with the use of the holder and level shown in Figure 4.6.

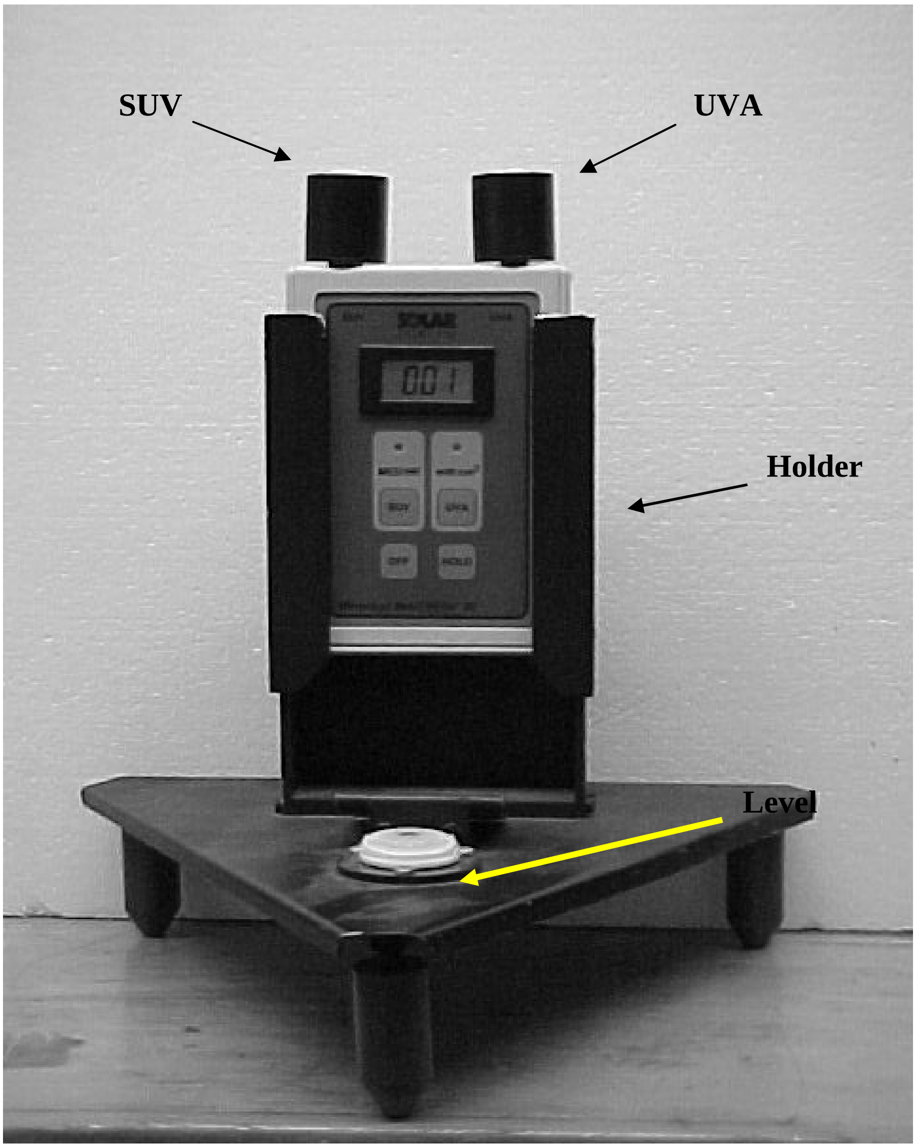


Figure 4.6. Robertson-Berger broadband meter.

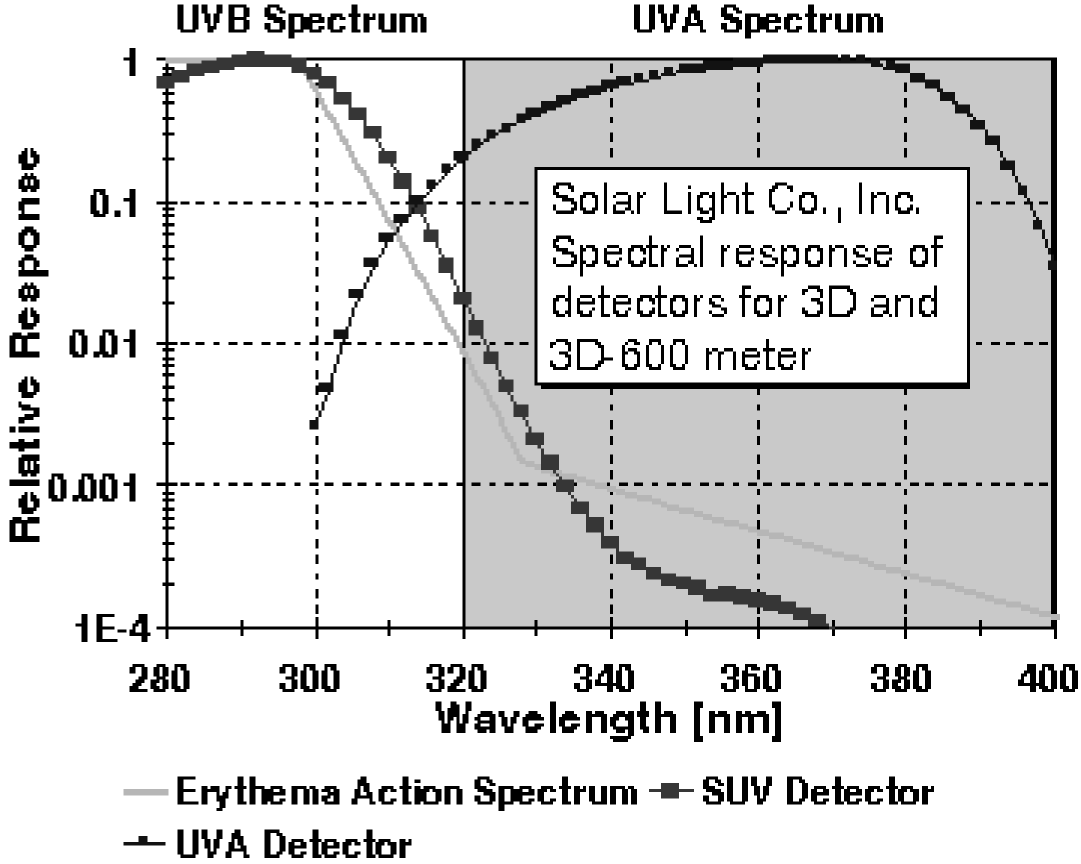


Figure 4.7. Spectral response of the SUV and UVA detectors of the Robertson-Berger meter (Solar, 2004).

4.2.1.4 Lux Meter

A handheld digital light meter (Figure 4.8) (model EMTEK LX-102, supplier, Walsh's Co., Brisbane, Australia) was used to measure the light intensity in the full sun and in the shade. The spectral response of the LX-102 is in accordance with the CIE photopic spectrum (CIE, 1990) with a range up to 50000 lux and an accuracy of ±5% (as stated by the manufacturer). The calibration standard provided by the manufacturer was used for the LX-102. These measurements were used to compare light intensity (lux) with UV irradiances provided by the RB meter.

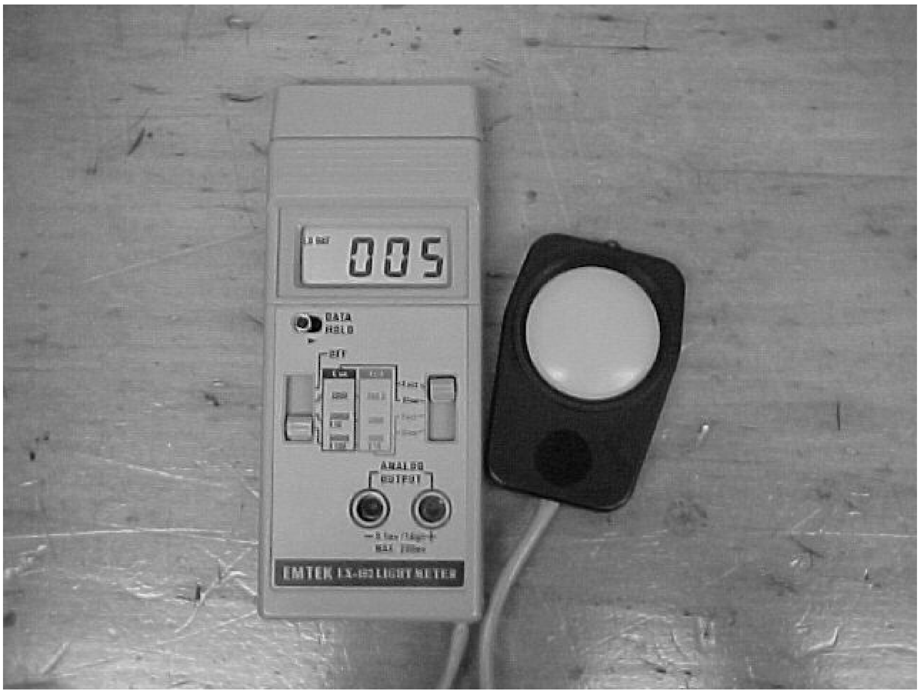


Figure 4.8. Visible intensity meter.

4.2.1.5 UV Spectroradiometer

The scanning UV spectroradiometer (model DTM300, Bentham Instruments, Ltd, Reading, UK) employed to calibrate the SUV meters 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. The spectroradiometer is housed in an envirobox that employs a Peltier heater/cooler unit to stabilise the enclosure to 23.0 ± 0.5 ^{o}C and automatically records the UV spectrum from 280 to 400 nm in 0.5 nm increments, every five minutes of the day. A PTFE (polytetrafluoro ethylene) diffuser with a reasonably clear view of the sky connected by an optical fibre to the input slit of the monochromator provides the input optics (Figure 4.9). This instrument is located on the same roof as the SUV meters. Data in IEEE format is sent to a computer in the laboratory at a distance of approximately 80 m by using GPIB extenders (model GPIB-130, National Instruments Australia) at the instrument and computer ends of the communication line to allow transmission of the data over this distance (Parisi and Downs, 2004). The BenWin+ software (Bentham Instruments, Reading, UK) provides the spectroradiometer control, data acquisition, display and manipulation.

The cosine response of the diffuser was tested by the manufacturer at 10^o steps and was found to have the associated errors of less than ±0.8% for a SZA up to 70^o and 3.3% for a SZA of 80^o. This spectroradiometer is calibrated monthly against three 150 W quartz tungsten halogen lamp with calibration traceable to the National Physical Laboratory, UK standard and wavelength calibrated against the UV spectral lines of a mercury lamp. The error due to wavelength variation is of the order of ±1.1% and the variation of the stability of the spectroradiometer output is 5.2% (Parisi and Downs, 2004).

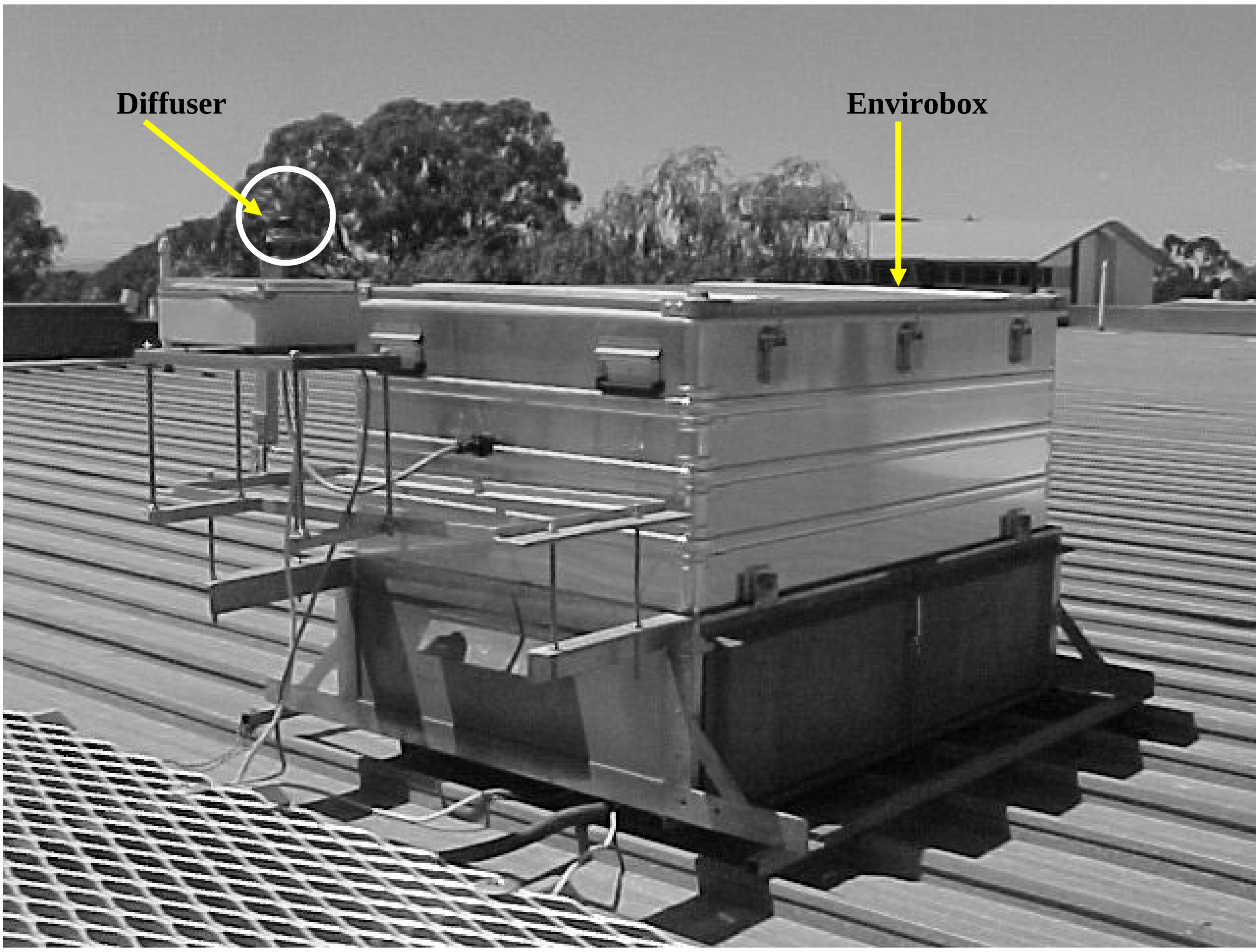


Figure 4.9. Scanning UV spectroradiometer permanently mounted outdoors.

4.2.2 Quantifying Cloud Cover

The amount of cloud cover was quantified with the use of the Total Sky Imager (TSI) (model TSI-440, Yankee Environmental Systems, MA, USA) (Figure 4.10). The TSI is currently mounted on top of a university building near the spectroradiometer and is setup to automatically collect data for SZA less than 80^{o} and to process this data to provide the fraction of cloud cover. The TSI has a charge coupled device (CCD) camera and software package that captures images into JPEG format data files, which are then analysed for fractional cloud cover. An example of an unprocessed and processed total sky image for quantifying the cloud cover is provided in Figure 4.11. Overload of the CCD is prevented by use of a shadow band that tracks the sun's movement to obscure the solar disc on the mirror. The CCD camera is mounted over the mirror by a thin pipe that can be seen as a thin black line from the bottom to the centre in both images in Figure 4.11. The shadow band and camera support are masked in the image processing. The position of the sun can be seen as the white dot on the shadow band. The system provides the cloud cover reading during all daylight hours with SZA less than 80^o at a user-defined interval of 5 minutes. The uncertainty of the TSI is estimated at ±10% for 95% of the time (Long et al., 2001).

Figure 4.10. Total Sky Imager.

Figure 4.11. Examples of an unprocessed and processed total sky image for quantifying cloud cover (31% cloud cover in this case).

4.2.3 UV Dosimetry

Davis et al (1976) first described the use of polysulphone film as a dosimeter for UV measurement. Due to the spectral response (CIE, 1992) that approximates the erythemal action spectrum (CIE, 1987) and the change in optical absorbency at 330 nm, polysulphone is of great use as an erythemal dosimeter. Polysulphone film is typically 40 μm in thickness and is generally mounted in a cardboard or PVC holder with an aperture of approximately 1.2 cm x 1.6 cm. Polysulphone undergoes a change in optical absorbency when exposed to wavelengths shorter than 330 nm (Davis et al, 1976). The change in optical absorbance can be correlated with the UV irradiance by simultaneously exposing a series of polysulphone dosimeters and measuring the solar UV irradiance with a spectroradiometer or broadband meter on an unshaded horizontal plane. UV exposure is calculated by measurement of the optical absorbance of the film at 330 nm before and after exposure to UV with the use of a spectrophotometer (model UV-1601, Shimadzu Co., Kyoto, Japan). A specifically fabricated dosimeter holder was employed in the spectrophotometer that allowed repositioning of each dosimeter at a reproducible location with respect to the instrument beam. From the spectroradiometer or broadband data and the change in optical absorbency (ΔA) at 330 nm a calibration curve for the polysulphone can be obtained. Three associated problems with polysulphone are: the dark reaction of the film; inconsistent film thickness; and surface contamination. These sources of error can be reduced by simply measuring the change in optical absorbency at a standard time after each exposure, calibrating each batch of polysulphone cast, and making sure the polysulphone film is clean and free of any surface contaminants.

For this research, a specifically constructed casting table using high quality controls was used to cast the polysulphone film. Dosimeters where then produced for this research, similar to that shown in Figure 4.12.

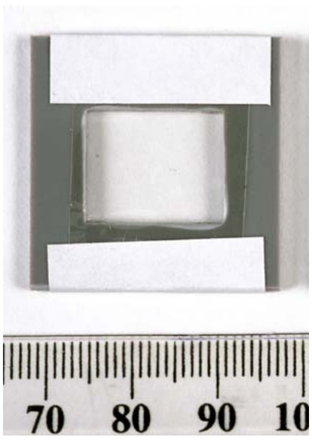


Figure 4.12. An example of a polysulphone dosimeter.

For this research, polysulphone dosimeters were employed to measure the erythemal UV exposure to specific anatomical facial sites. Polysulphone dosimeters were placed at sixteen different facial sites, as shown in Figure 4.13, on a manikin head form in order to simulate a human head. There was negligible difference in the measured albedo between the base and head form. These facial sites have been employed based on similar sites selected in previous research to quantify the erythemal UV facial exposures (Kimlin et al, 1998). The use of manikin headforms have been previously employed in earlier research to quantify the UV exposures in different environments (for example Kimlin et al, 1998; Parisi et al, 2000a; Downs et al, 2000). 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. Polysulphone dosimeters were attached to the vertex of the head of each manikin in order to measure both personal exposures for the specific site and also to measure ambient UV levels on a horizontal plane. 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 of Toowoomba, Australia. A series of measurements were conducted in summer and winter to account for the variation in exposure levels, SZA and atmospheric conditions experienced during the different seasons.

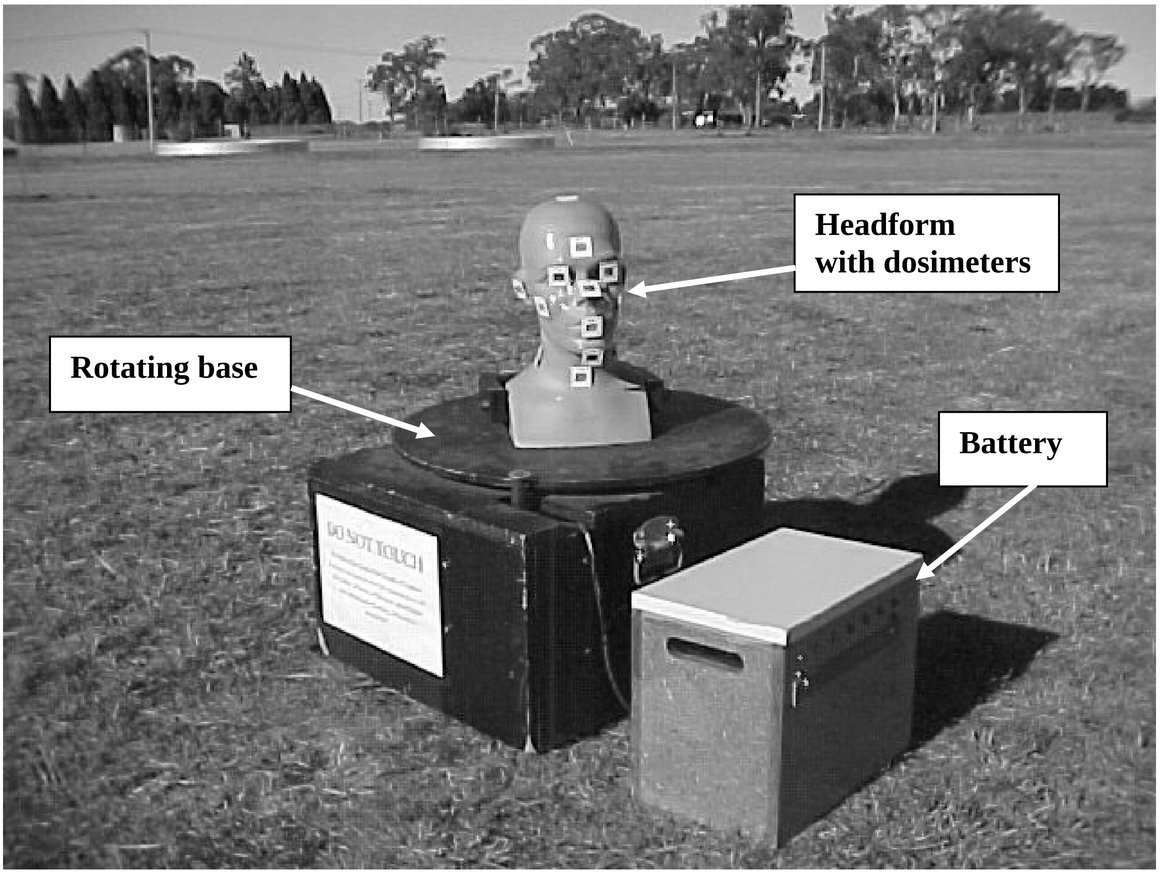


Figure 4.13. Headform with dosimeters on a rotating base.

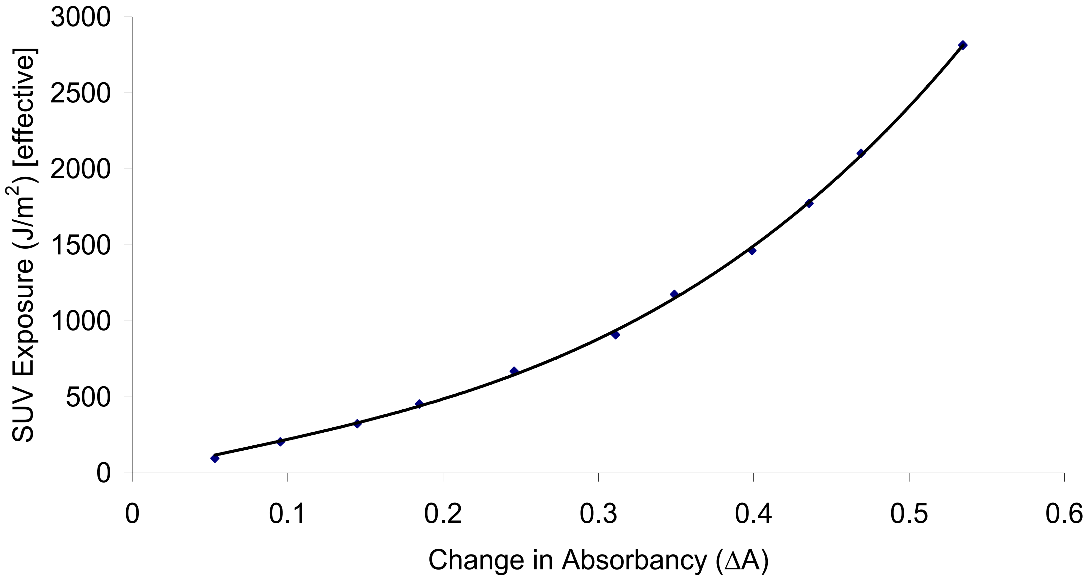
For each dosimeter, the absorbances were measured at four different sites over the dosimeter in order to minimise errors due to any possible minor variations in the polysulphone film over the size of the dosimeter (Diffey, 1989). The polysulphone dosimeters were calibrated with the UV spectroradiometer described in section 4.2.1.5 using an approach similar to Parisi and Kimlin (2004). The calibration curves for summer and winter are shown in Figure 4.14. Calibration of the dosimeters was done for both summer and winter to reduce the errors associated with the change in the shape of the solar UV spectrum. The regression curves fitted to the summer, SUV_S, and winter, SUV_W, data are:

$$SUV_S = 14420(\Delta A)^3 - 2136(\Delta A)^2 + 2281.8(\Delta A) \quad (4.1)$$

$$SUV_W = 16825(\Delta A)^3 + 917.8(\Delta A)^2 + 1866.1(\Delta A) \quad (4.2)$$

both with an R^2 greater than 0.99.

(a)



(b)

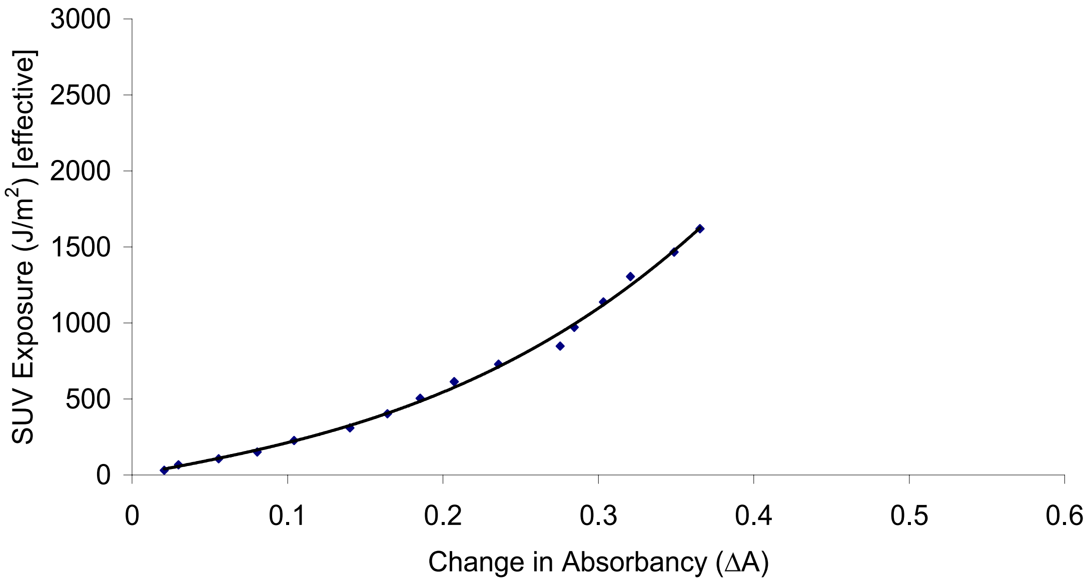


Figure 4.14. Dosimeter calibration curves for (a) summer 2004 and (b) winter 2004.

4.3 Shade Structures

4.3.1 Public Shade Structures

Three different public shade structures were employed in this research and were located at varying public locations around the city of Toowoomba, Australia. The three structures (shown in Figure 4.15) were chosen so a range of differently sized public shade structures could be investigated (comparisons of the solar UV measured near the shade structures compared to that measured by the global UV meters are provided in Appendix B). To a first order, the results are applicable to other shade structures of the same approximate dimensions that reduce the amount of sky view by the same approximate amount. None of the shade structures had any surrounding vegetation or other structures. The structures were three different gazebos of varying size and will be referred to as the small, medium and large shade structures. Details of the shade structures are as follows:

- Small Shade Structure (Figure 4.15a): The small shade structure is 2.55 m wide at the sides, 2.28 m high at the eaves and approximately 3.10 m high at the apex. The overhang of the roof is approximately 0.69 m, making the roof area of the small shade structure 15.5 m^2. This structure was chosen because it is situated between public sporting ovals where spectators seek to shade themselves.

- Medium Shade Structure (Figure 4.15b): The medium shade structure is of hexagonal shape with sides measuring 2.16 m wide, 2.11 m high at the eaves, and approximately 3.31 m high at the apex. The overhang of the roof is approximately 0.55 m, making the roof area 19.1 m^2. This structure was chosen due to its location in a public park with no other forms of shade available.

- Large Shade Structure (Figure 4.15c): The large shade structure is of an elongated octagonal shape with the longest sides of 2.30 m and the shortest sides measuring 2.10 m. The structure was 2.10 m high at the eaves, 2.85 m high at the apex and had an approximate overhang of 0.69 m. The roof area of the large shade structure was approximately 32.1 m^2. This structure was chosen because it is located at the corner of a public sports field where people will seek shade during sporting events.

The albedo of the grass surrounding the shade structures ranged from 4% in the shade to 6% in full sun, while the albedo of the concrete beneath the shade structure stayed at approximately 10% for shade and full sun. The albedo was calculated by comparing the upwelling and downwelling irradiances in both full sun and shade at a distance of approximately 0.3 m from each of the surfaces.

The tables, seats and underside of the roofs also contributed varying amounts to the UV levels beneath the structure due to scattering. For the small shade structure the albedo of the table and seats was approximately 11% in the full sun and up to 7% in the shade, with the albedo of the underside of the roof approximately 2%. The albedo of the tables and seats in the medium and large shade structures was approximately 6% in full sun and 4% in the shade, with the underside of the roofs roughly 2%.

When positioned in the centre of the shade structures the amount of sky view obstructed by the shade structures was calculated as 30%, 36% and 42% for the small, medium and large shade structures respectively. This percentage was calculated as the area of the roof divided by the area of the roof and the sides.

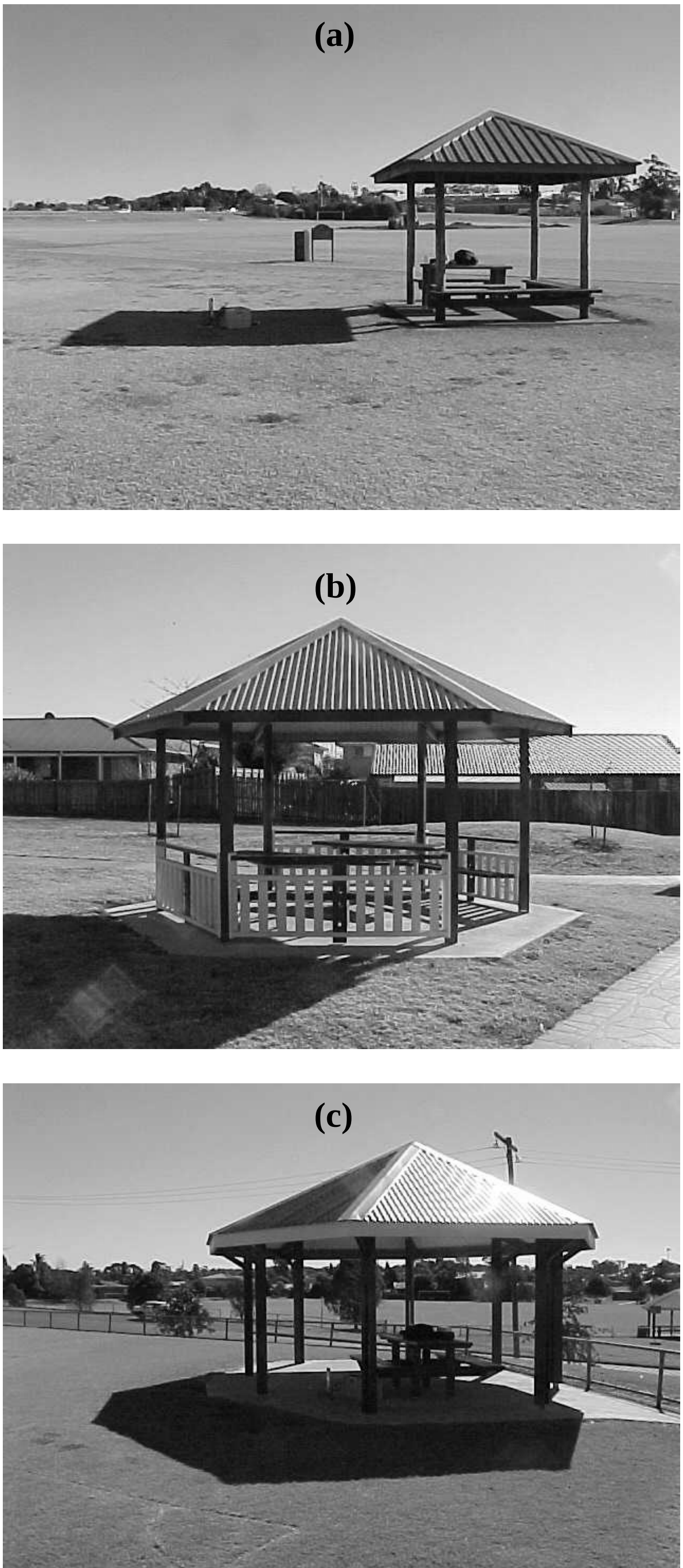


Figure 4.15. The (a) small, (b) medium and (c) large public shade structures.

4.3.2 Shade Structure Model

The physical dimensions of the medium sized public shade structure (Figure 4.15b) were used to build a half-size scale model (Figure 4.16) 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 SUV and UVA irradiances for the model and full-size shade structures were found to be less than 3%. 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. Scaled down versions of the tables and seats were also constructed. The model structure was painted the same colour as the full size structure. The albedo of the roofing, ground and other structural materials were similar to that observed for the full size structure.

Figure 4.16. Scale model shade structure with headforms in place.

4.3.2.1 Polycarbonate Sheeting

Three types of polycarbonate (PC) sheeting were considered for this research to improve the UV protection provided by a structure. This was 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 (Turnbull et al, 2003). 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.

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 4.17. Maximum transmission values were observed in the near infrared region with 89%, 64% and 49% for the clear, bronze tint and grey tint, respectively. UV transmission of less than 1% was observed for wavelengths below 384 nm, 391 nm and 391 nm for the clear, grey and bronze tints, respectively. Despite most of the polycarbonates being virtually transparent in the near infrared and visible wavebands, all samples had zero UVB transmittance and negligible UVA transmittance below 365 nm. The low ultraviolet transmission values indicate that these polymeric materials provide substantial protection against direct solar UV.

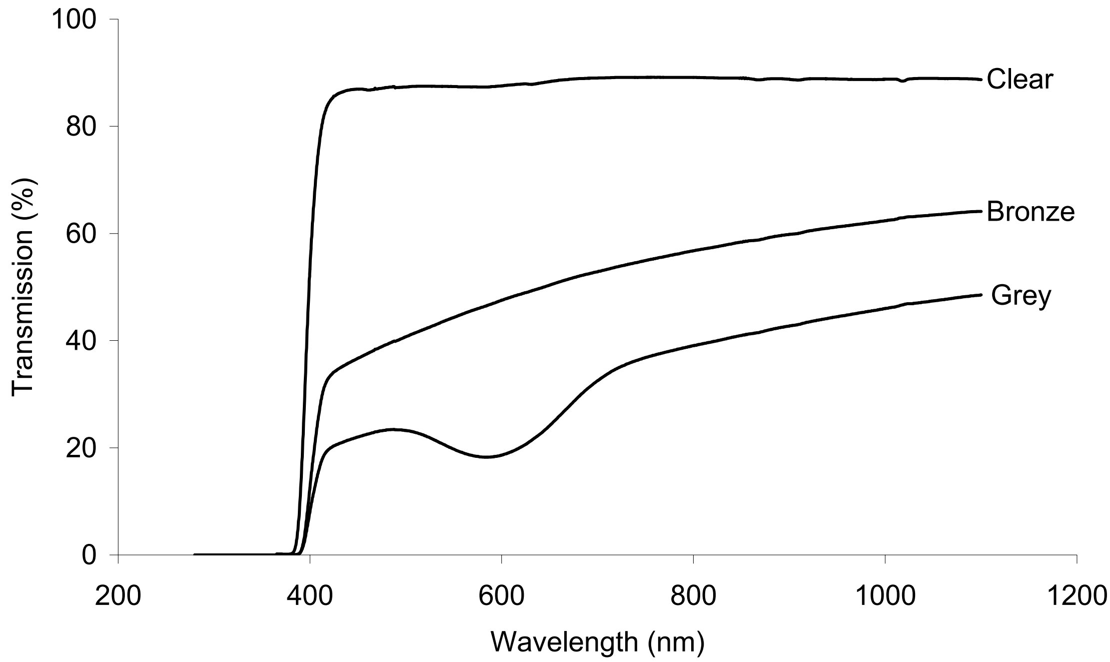


Figure 4.17. The spectral transmission properties of the three specific types of PC sheeting used.

4.3.3 Shade Structures and Vegetation

The shade structures used for the research on the effects of vegetation surrounding the structure are based on the small shade structure described in section 4.3.1. These shade structures were utilized because they each had varying degrees of evergreen vegetation surrounding them and were situated at public sporting fields located in the city of Toowoomba, 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 and lack of seasonal change in density of the leaves and the height and width that it grows to. The dimensions of the structure are described in section 4.3.1.

Four shade structures of the same type were used for this specific research into the effects of surrounding vegetation (Figure 4.18) (Turnbull et al, 2003; Turnbull and Parisi, 2004a). One shade structure had no surrounding vegetation and was used as a control (a). The other three structures had varying amounts of vegetation covering different sides of the shade structures. Shade structure (b) had varying amounts of vegetation on the north-western, western and south-western sides. Shade structure (c) 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 (d) was located at the south-western edge of a sports field, with vegetation to the southern, south-western and western directions.

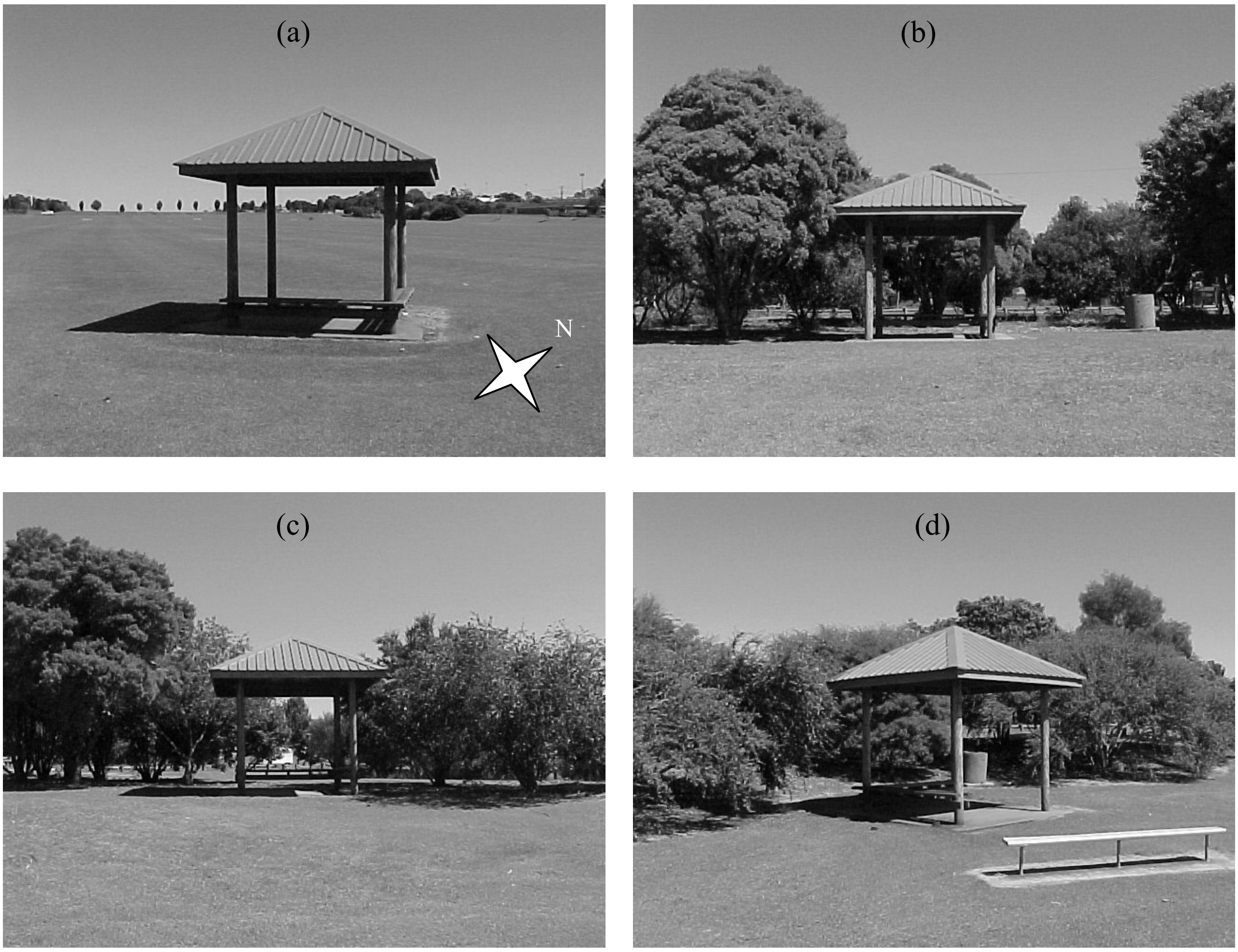


Figure 4.18. The four shade structures used with varying levels of surrounding vegetation.

4.4 Chapter Discussion

This chapter has detailed the materials and instruments used for this project. These have ranged from complex scanning spectroradiometers calibrated to traceable calibration standards, through to radiometers, dosimeters, cloud cameras and scale models of public shade structures and manikin headforms. Also outlined in this chapter has been the methods used to gather all the data for the research that is presented in the following chapters.

CHAPTER 5

QUANTIFYING DIFFUSE AND GLOBAL SOLAR UV

5.1 Introduction

With new emphasis being placed on the diffuse component of incident terrestrial ultraviolet radiation and human exposure, more research is needed to better explain how diffuse UV changes according to varying factors. A number of factors influence the levels of diffuse UV and global UV that humans are exposed to, namely clouds, surface albedo, solar zenith angle, amount of sky view and atmospheric particles and aerosols. For cloudy conditions, an indication of the relative proportion of diffuse UV in global UV is related to the time of day and the amount of cloud in the sky. Otherwise, for cloud free skies and surfaces not covered by high albedo coverings, namely snow, diffuse SUV levels can be predicted employing the relevant expressions developed in this research to evaluate the diffuse SUV and the ratio of diffuse to global SUV as a function of SZA. This is the first research to concurrently measure broadband global and diffuse SUV with the aim of understanding the influences of the UV under shade structures.

5.2 Diffuse and Global SUV Data

5.2.1 Diffuse and Global SUV for all Sky Conditions

The 2003 data sets for diffuse and global SUV for all sky conditions and a changing SZA are shown in Figure 5.1 and 5.2, respectively. The data in Figure 5.1 and 5.2 corresponds to over 29,700 data points for diffuse and over 43,100 data points for global SUV. Differences between diffuse and global SUV levels are more pronounced for the lower SZA seen predominantly in the middle of the day during summer. For a SZA of approximately 5^{o}, average irradiances were 154.0±40.9

mW/m^2 and 332.1±115.7 mW/m^2 for diffuse and global SUV irradiances respectively. However, for the larger SZA of approximately 80°, average SUV levels were 4.1±1.2 mW/m^2 and 5.0±1.3 mW/m^2 for diffuse and global SUV respectively.

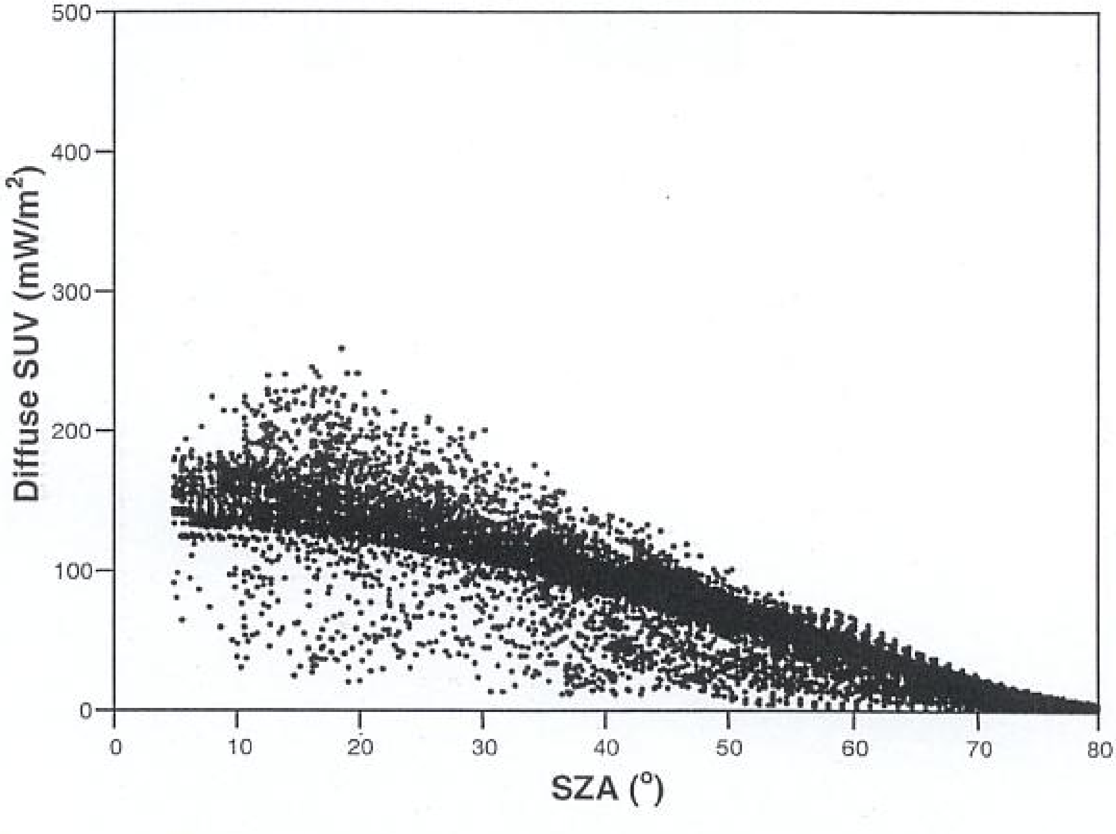


Figure 5.1. Diffuse SUV as a function of SZA for all sky conditions.

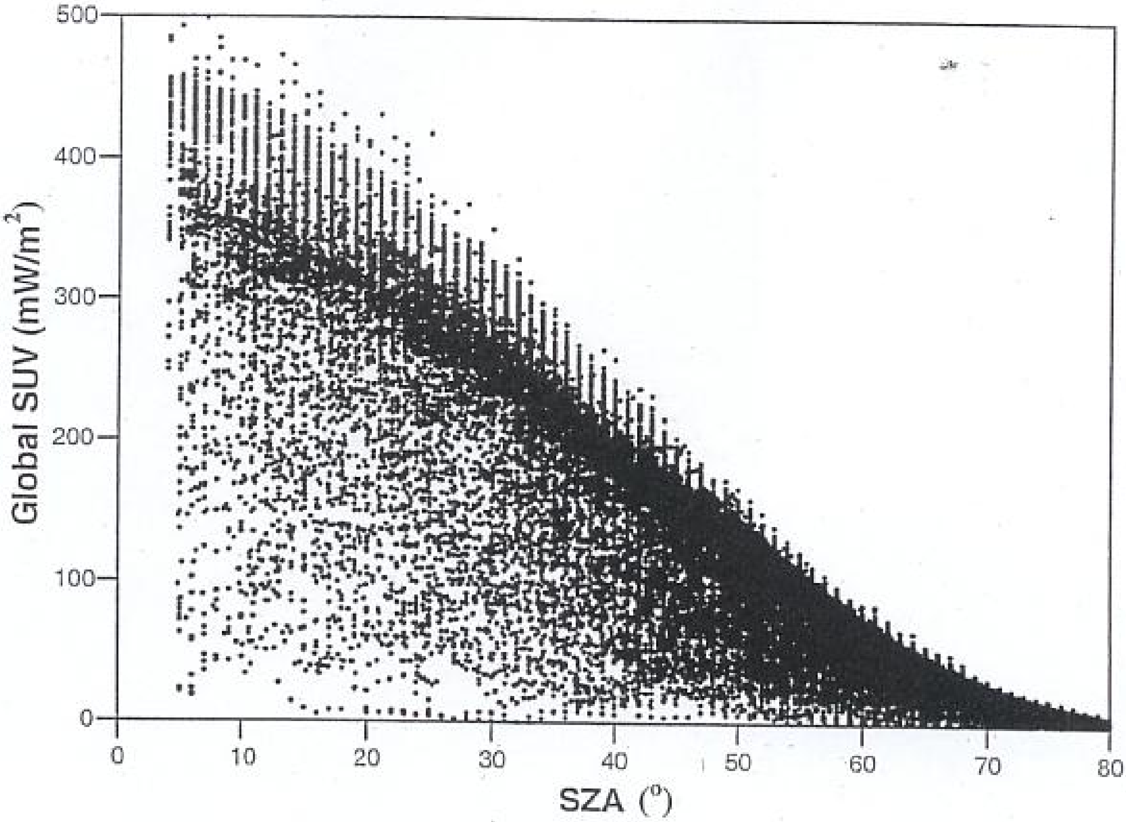


Figure 5.2. Global SUV as a function of SZA for all sky conditions.

The ratios of SUV_{Diff} to SUV_{Glob} are provided in Figure 5.3 for all sky conditions and a changing SZA of 5° to 80°. Ratios provided show that for a small SZA of approximately 5°, the average proportion of diffuse SUV in global SUV was 0.55±0.19. For the larger SZA of approximately 80°, the average proportion of diffuse SUV found in global SUV was 0.82±0.09.

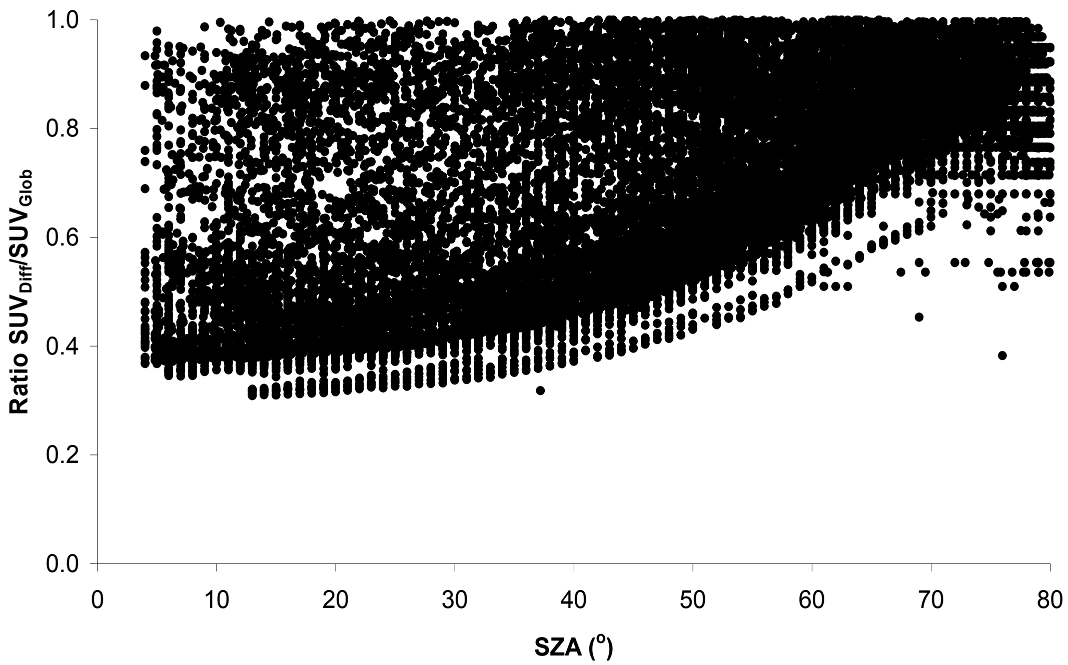


Figure 5.3. Ratios of SUV_{Diff}/SUV_{Glob} for all sky conditions as a function of SZA.

Ratios of SUV_{Diff} to SUV_{Glob} for cloud fraction of 0.9 to 1.0 (90 to 100%) and 0.1 to 0.2 (10 to 20%) are shown in Figure 5.4. Figure 5.4 illustrates that for a cloud fraction of 0.9 to 1.0, the diffuse SUV fraction in global SUV varied from approximately 0.68 to 1.00 irrespective of SZA with an average of 0.88±0.07. Variation in the data for a varying cloud fraction of 0.9 to 1.0 is most likely due to changes in cloud type and also optical depth of the cloud cover. For a changing cloud fraction of 0.1 to 0.2, a general increasing trend in the proportion of diffuse SUV in global SUV is observed for an increasing SZA. For the smaller SZA of approximately 5^{o}, the diffuse SUV fraction in global UV ranged from approximately 0.39 to 0.53. While the ratios ranged from 0.92 to 1.00 for the larger SZA of approximately 80^{o}. Therefore, cloud fraction and SZA play a pivotal role in determining the proportionality of diffuse SUV in global SUV.

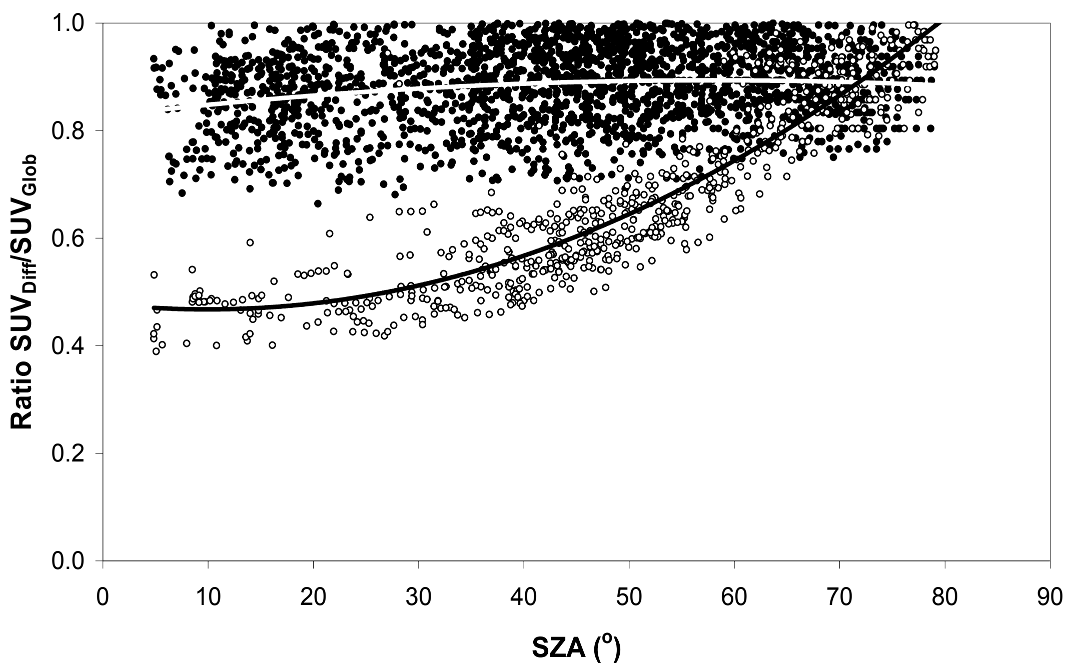


Figure 5.4. Ratios of SUV_{Diff}/SUV_{Glob} for varying cloud fractions of 0.1 to 0.2 (○) and 0.9 to 1.0 (●).

5.2.2 Clear Sky Data

The variation in diffuse and global SUV for clear sky conditions (less than 2% cloud cover) and a changing SZA are shown Figure 5.5 and 5.6, respectively. From the data collected for all sky conditions, over 5,400 data points for diffuse and over 9,300 data points for global SUV were classified as cloud free. The variation in data points between global and diffuse SUV is due to two reasons: (i) the misalignment of the shadowband; and (ii) malfunctioning equipment. In Figure 5.6 there is distinct bimodal distribution at SZA < 40^o, this distribution can be accounted for by changes in ozone and aerosol levels, and loss of global SUV data for a specific period during 2003. From Figure 5.5 and 5.6, differences between diffuse and global SUV levels are more pronounced for the lower SZA. For the cloud free cases and a SZA of approximately 5^o, average diffuse and global SUV levels were 141.4±1.7 mW/m^2 and 359.6±12.8 mW/m^2, respectively. However, for the larger SZA of approximately 80^o, average SUV levels were 4.9±0.7 mW/m^2 and 5.7±0.8 mW/m^2 for diffuse and global SUV respectively. The regression curves fitted to the diffuse SUV (SUV_{Diff}) and global SUV (SUV_{Glob}) for cloud free conditions are:

$$SUV_{Diff} = 4.218\text{x}10^{-7}(SZA)^5 - 8.610\text{x}10^{-5}(SZA)^4 + 6.574\text{x}10^{-3}(SZA)^3 - 2.457\text{x}10^{-1}(SZA)^2 + 2.856(SZA) + 128.205 \quad (5.1)$$

$$SUV_{Glob} = 3.726\text{x}10^{-7}(SZA)^5 - 7.637\text{x}10^{-5}(SZA)^4 + 6.864\text{x}10^{-3}(SZA)^3 - 3.301\text{x}10^{-1}(SZA)^2 + 1.947(SZA) + 358.344 \quad (5.2)$$

both with an R^2 of 0.99.

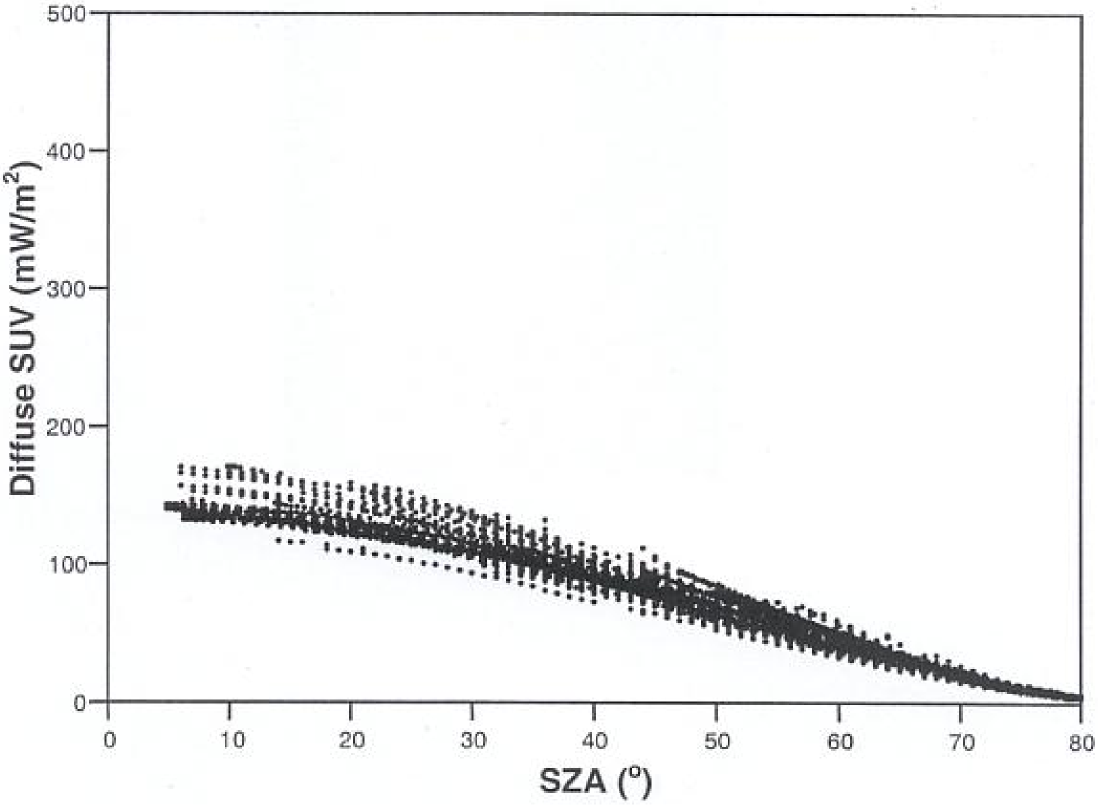


Figure 5.5. Diffuse SUV as a function of SZA for clear sky conditions.

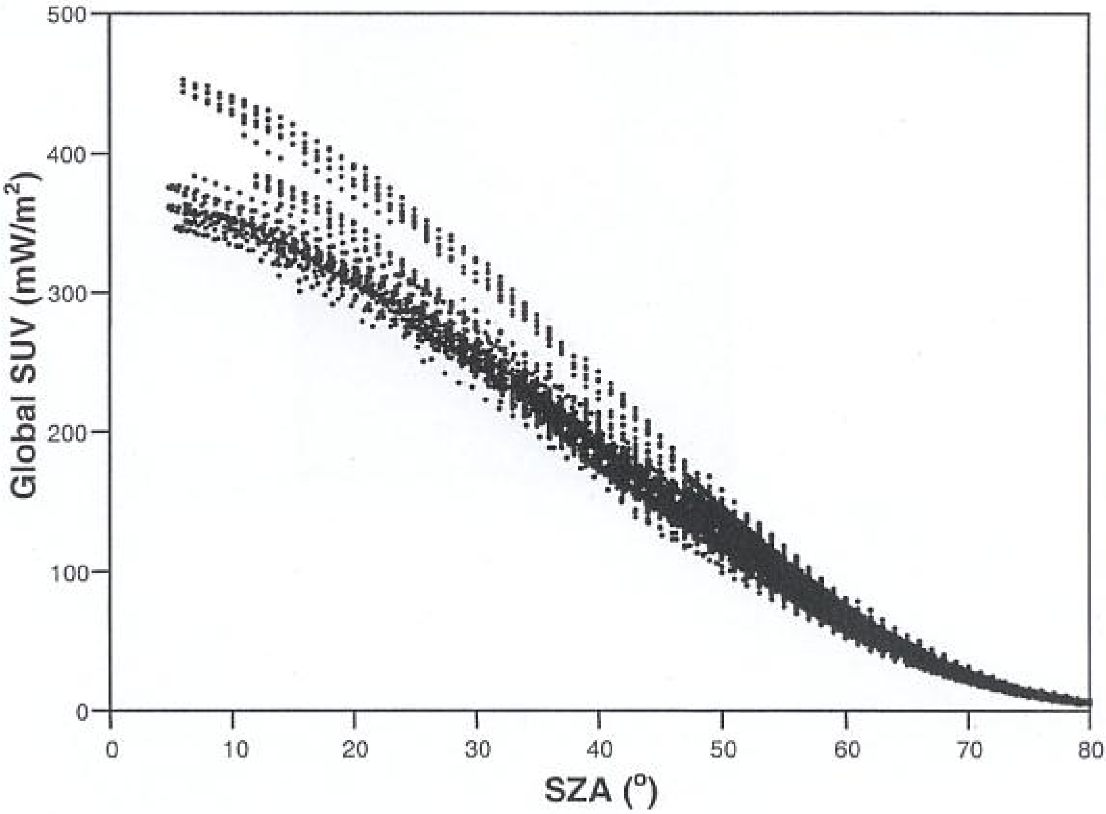


Figure 5.6. Global SUV as a function of SZA for clear sky conditions.

The ratios of SUV_{Diff} to SUV_{Glob} are provided in Figure 5.7 for clear sky conditions and a changing SZA of 5^o to 80^o. Ratios provided show that for a small SZA of approximately 5^o, the average proportion of diffuse SUV in global SUV was 0.39±0.01. For the larger SZA of approximately 80^o, the average percentage of diffuse SUV found in global SUV was 0.90±0.11. The regression curve fitted to the data is:

$$\frac{SUV_{Diff}}{SUV_{Glob}} = -8.00\text{x}10^{-8}(SZA)^4 + 1.00\text{x}10^{-5}(SZA)^3 - 6.00\text{x}10^{-4}(SZA)^2 + 1.33\text{x}10^{-2}(SZA) + 0.31 \quad (5.3)$$

with an R^2 of 0.93.

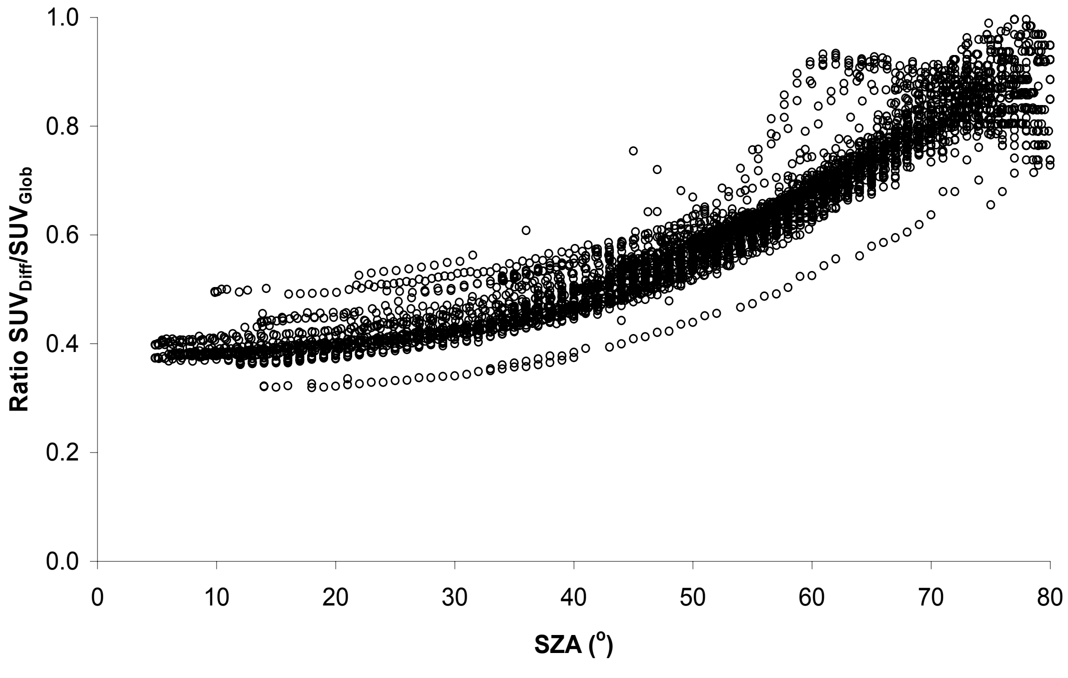


Figure 5.7. Ratios of SUV_{Diff}/SUV_{Glob} for clear sky conditions as a function of SZA.

When comparing global SUV data in Figures 5.2 and 5.6, enhancement of SUV above that of clear sky conditions does occur. This enhancement may be due to specific cloud positioning and orientations as previously reported (for example Parisi and Downs, 2004). Factors that may have influenced the variation of SUV levels shown in Figure 5.5 and 5.6 for cloud free conditions are changes in atmospheric ozone and aerosol concentrations over the measurement period and also the ±10% uncertainty of the broadband instruments.

5.2.3 Ozone Data

Total column ozone levels over Toowoomba as recorded by TOMS (TOMS, 2004) from January 2003 to December 2003 are shown plotted in Figure 5.8. For all sky conditions, ozone levels ranged from 241 to 338 DU during the measurement period with an average ozone concentration of 278±21 DU. From the plotted data, the lowest atmospheric ozone concentrations were observed from May to June. Whereas, the highest atmospheric ozone concentrations observed were for the months of September to November.

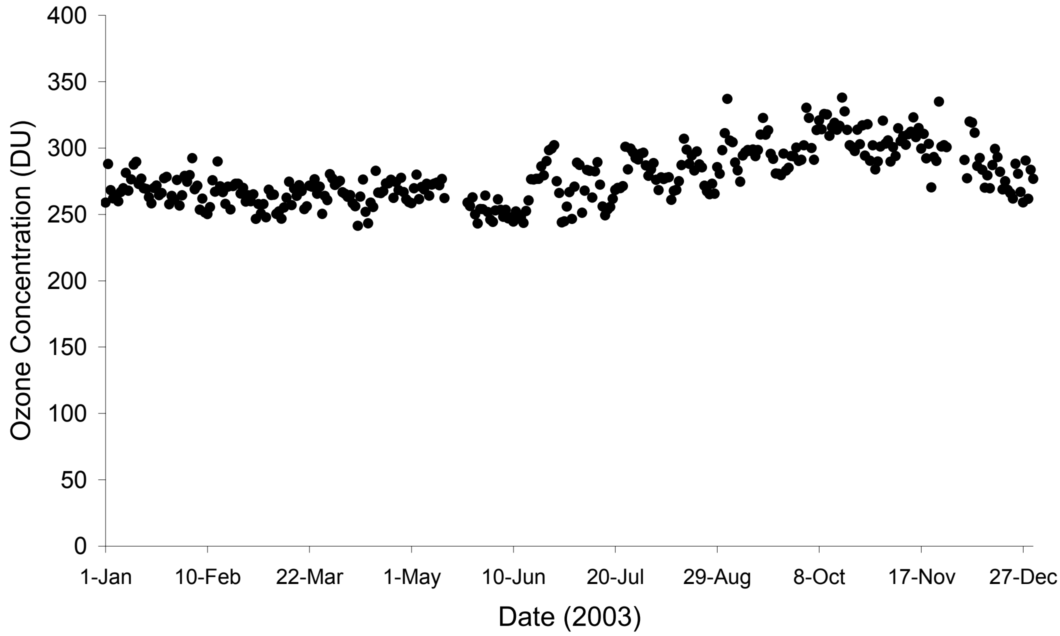


Figure 5.8. Atmospheric ozone levels provided by TOMS from January to December 2003.

5.2.4 Aerosol Data

The aerosol index for 2003 for the skies over Toowoomba was also obtained from TOMS (TOMS, 2004). Measurements of irradiance were conducted at 331 nm by TOMS and then compared to the theoretical irradiance at 360 nm. This is done to quantify the extent to which the wavelength dependence of backscattered UV radiation from an atmosphere containing aerosols differs from that of a pure molecular atmosphere. Figure 5.9 shows the aerosol index from January to December 2003. Over this period, the aerosol index ranged from -4.30 to 4.95 with an average of 0.13±1.32. The lowest levels were generally seen during the winter months in the middle of the year and the highest were observed during the southern hemisphere summer months.

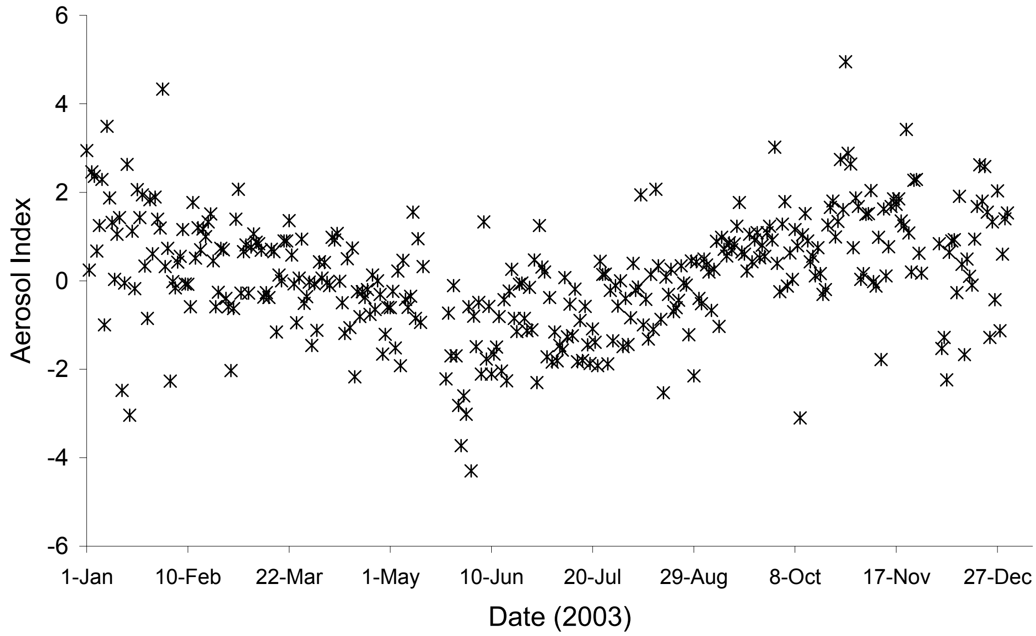


Figure 5.9. Aerosol index for Toowoomba from January to December 2003.

5.2.5 Radiation Amplification Factors (RAF)

The RAF values for the clear sky collected data were calculated by applying a power function to the data for each SZA and then integrating equation 2.1 to extract R*sza*. The results for each SZA group were extrapolated from the data shown in Figure 5.10 and are provided in Table 5.1 with the appropriate standard error. A simple trigonometric correction was applied to all the data before calculation of the RAF to remove any variation associated with changes in the Earth-Sun distance (see Madronich, 1993, pp.22). During the measurement period, the solar zenith angle ranged from 5^o to 80^o. Only a small number of clear sky diffuse SUV data points were obtainable for the data set for a SZA of 10^o. Therefore, the standard error associated with the RAF value for this specific SZA of 10^o is larger than for the other SZA groups. For the SZA groups of 10^o, 20^o, 30^o, 40^o, 50^o, 60^o, 70^o and 80^o, the associated RAF values are 0.84±0.40, 0.74±0.15, 0.71±0.13, 0.75±0.10, 0.95±0.07, 1.02±0.10, 0.82±0.11 and 0.95±0.17 respectively. The variation of these RAF values may be due to a number of factors, mainly, changes in the height distribution of ozone and seasonal variations in tropospheric ozone levels (Mackenzie et al., 1991). Atmospheric ozone concentrations and aerosol index values for the diffuse SUV data used to calculate the RAF values are shown in Figures 5.11 and 5.12 respectively. For the diffuse SUV clear sky data collection days, atmospheric ozone concentration ranged from 243 to 330 DU with an average of 277±20 DU and the aerosol index ranged from -2.48 to 2.58 with an average of 0.13±1.2.

Table 5.1. Experimental values for the RAF for diffuse SUV with the standard error.

SZA	RAF
10^o	0.84±0.40
20^o	0.74±0.15
30^o	0.71±0.13
40^o	0.75±0.10
50^o	0.95±0.07
60^o	1.02±0.10
70^o	0.82±0.11
80^o	0.95±0.17

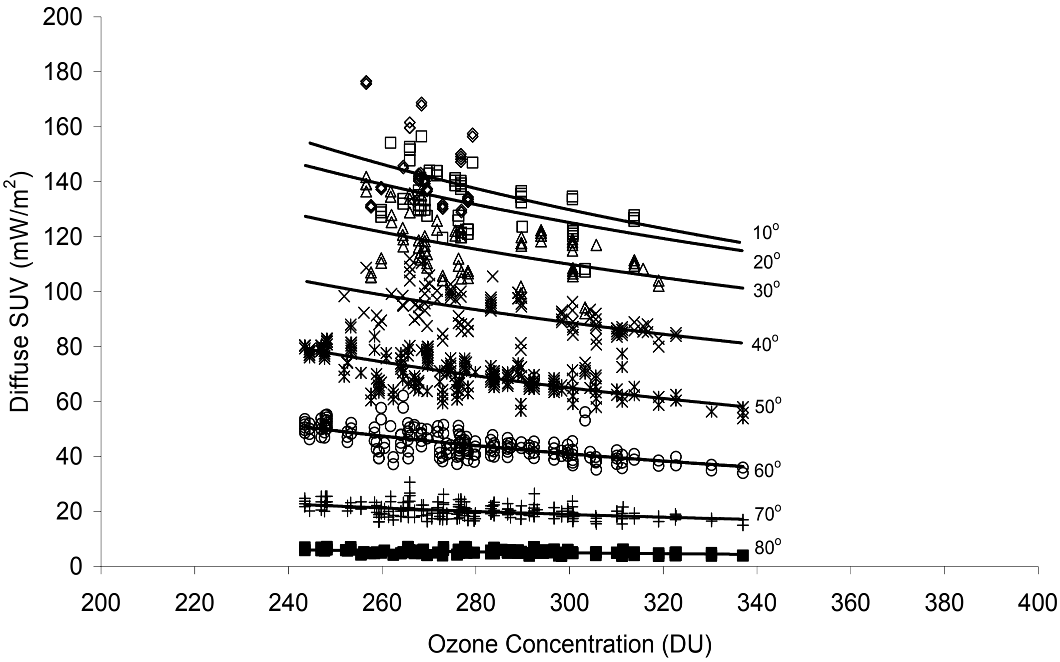


Figure 5.10. Diffuse SUV irradiance as a function of ozone concentration for specific SZA of 10°, 20°, 30°, 40°, 50°, 60°, 70° and 80°.

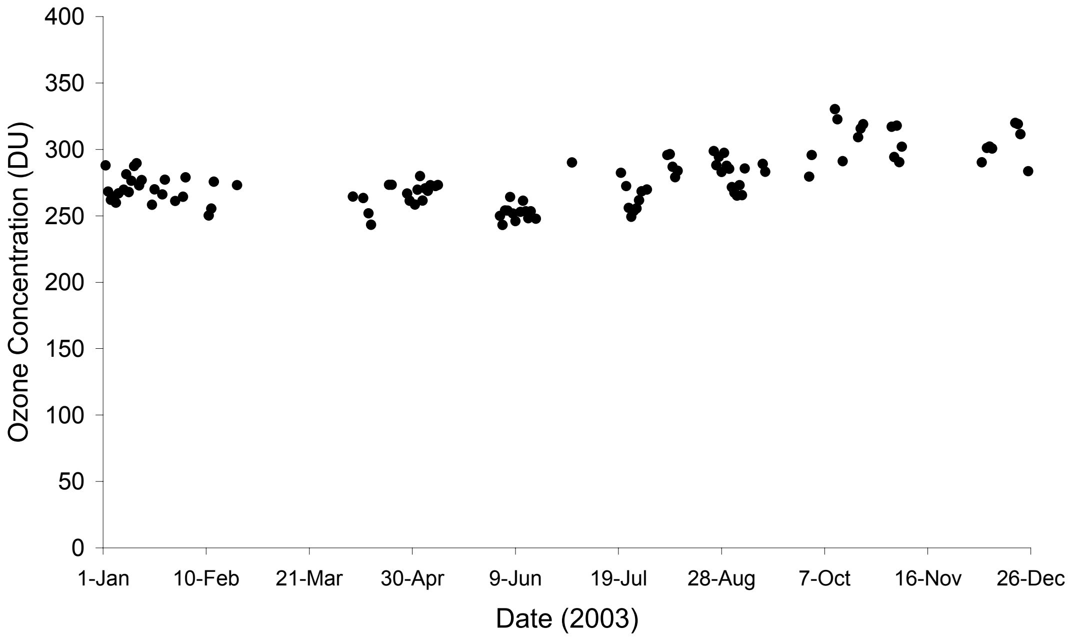


Figure 5.11. Atmospheric ozone concentration for the days when clear sky diffuse SUV data was recorded.

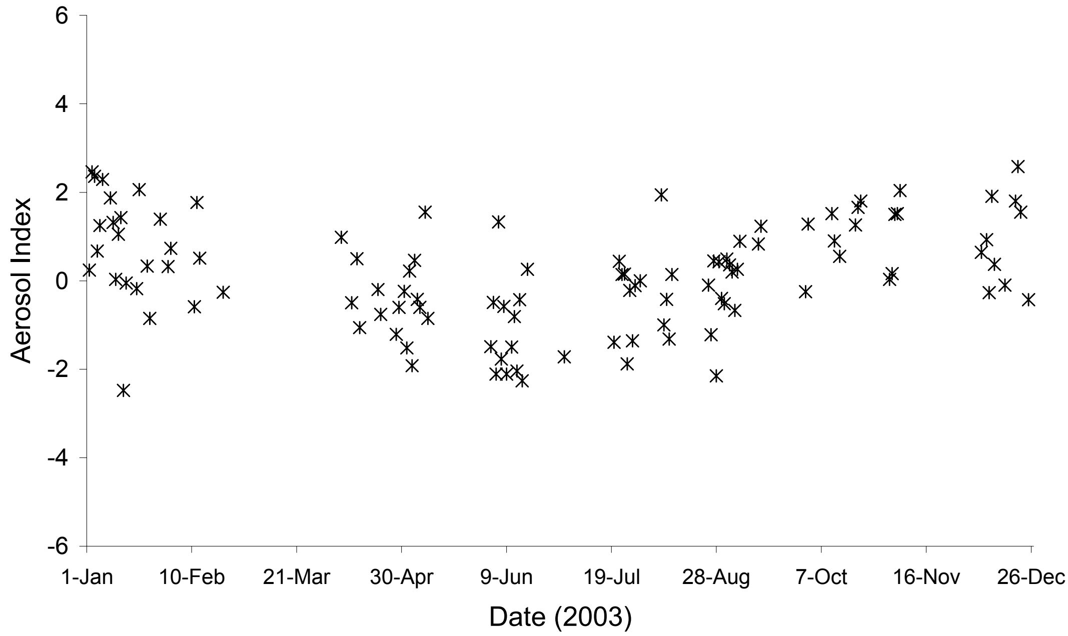


Figure 5.12. Aerosol index for the days when clear sky diffuse SUV data was recorded.

5.3 Chapter Discussion

Broadband diffuse and global erythemal UV (SUV) and cloud cover were measured at five minute intervals for a 12 month period at a Southern Hemisphere site and for a solar zenith angle (SZA) range of 5^o to 80^o. Measurements of diffuse SUV and global SUV for all sky conditions and a changing SZA of 5^o to 80^o showed that for a small SZA of approximately 5^o, variation in the proportion of diffuse SUV in global SUV ranged from 35% to 100%. For clear sky conditions, variation in the proportion of diffuse SUV in global SUV ranged from 37% to 40%. For the larger SZA of approximately 80^o, the percentage of diffuse SUV found in global SUV ranged from 55% to 100%, for all sky conditions and from 72% to 100% for clear sky conditions. Empirical non-linear expressions as a function of SZA have been developed for clear sky conditions to allow the evaluation of the diffuse SUV and the ratio of diffuse to global SUV. Ratios of diffuse SUV to global SUV show that for the smaller SZA seen generally during summer (approximately 5^o to 12^o), the proportion of diffuse SUV found in the global SUV remained reasonably stationary at approximately 39% for clear sky conditions. For the larger SZA of 70^o to 80^o, the ratio of diffuse SUV to global SUV increases rapidly up to 100%. A number of factors influence the levels of diffuse UV and global UV that humans are exposed to, namely clouds, surface albedo, solar zenith angle, amount of sky view and atmospheric particles and aerosols. For cloudy conditions, an indication of the relative proportion of diffuse UV in global UV is related to the time of day and the amount of cloud in the sky.

Previous research has provided calculated RAF values for global SUV for a changing SZA. Mackenzie et al. (1991) calculated RAF values of approximately 1.11 to 1.39 for a SZA of 30^o and 1.15 to 1.34 for a SZA of 50^o. While Blumthaler et al. (1995) calculated RAF values of 1.01±0.11 for a solar elevation of 60^o and 0.90±0.05 for a solar elevation of 40^o. RAF values calculated from this research for diffuse SUV were less than those from previous research into global SUV, as was expected. Because the direct component of the solar irradiance is blocked and therefore the RAF values for the diffuse SUV show how variations in ozone concentrations will affect the scattered component, which will be to a lesser extent. For a SZA of 30^o and 80^o, the RAF's for diffuse SUV were 0.71±0.13 and 0.95±0.17. From this research, it can be concluded that decreases in atmospheric ozone concentrations have an increasing effect on diffuse SUV levels; however this is not to the same extent as global SUV.

CHAPTER 6

SHADE STRUCTURES AND SOLAR RADIATION

6.1 Introduction

Quantification of the UV and visible radiation environment beneath shade structures is important. While direct UV and visible radiation from the Sun is generally reflected or absorbed by the shade structure, the diffuse component is still present in the shade. However, the relative proportion of diffuse to direct is significantly different when comparing UV and visible radiation, as described in chapter 3. Over exposure to diffuse UV radiation may cause a number of short term and long term conditions, such as erythema and photokeratitis. There is currently insufficient quantitative knowledge and research on public shade structures and their efficiency at reducing personal UV exposure. The following sections of this chapter present the data sets for the handheld broadband meters and dosimetric field measurements of solar radiation beneath and around the various types of shade structures described in chapter 4.

6.2 Shade Structures and UV

SUV and UVA field measurements conducted beneath the three public shade structures described in section 4.3.1 are shown in Figures 6.1 and 6.2. These Figures are based on the maximum UV levels in the centre of the shade obtained from both the vertical and horizontal measurements. The horizontal plane received the highest SUV levels for the SZA of 28^{o} to 75^{o}, 42^{o} to 76^{o}, and 50^{o} to 76^{o} for the small, medium and large structures respectively. This was due to the angle of the sun causing the shade created by the shade structure to be outside the structure. As the SZA decreased, the levels of UV in the shade decreased on the horizontal plane and increased for the vertical planes. For the small shade structure, the vertical plane measurements directed to the west were the highest levels in the shade for a SZA greater than 28°. For the medium and large shade structures, the measurements directed to the west and south were the highest levels in the shade after roughly 42° and 50° respectively. This apparent increase in vertical plane measurements was due to the decrease in sky view on the horizontal plane which in turn decreased the levels of UV on the horizontal plane.

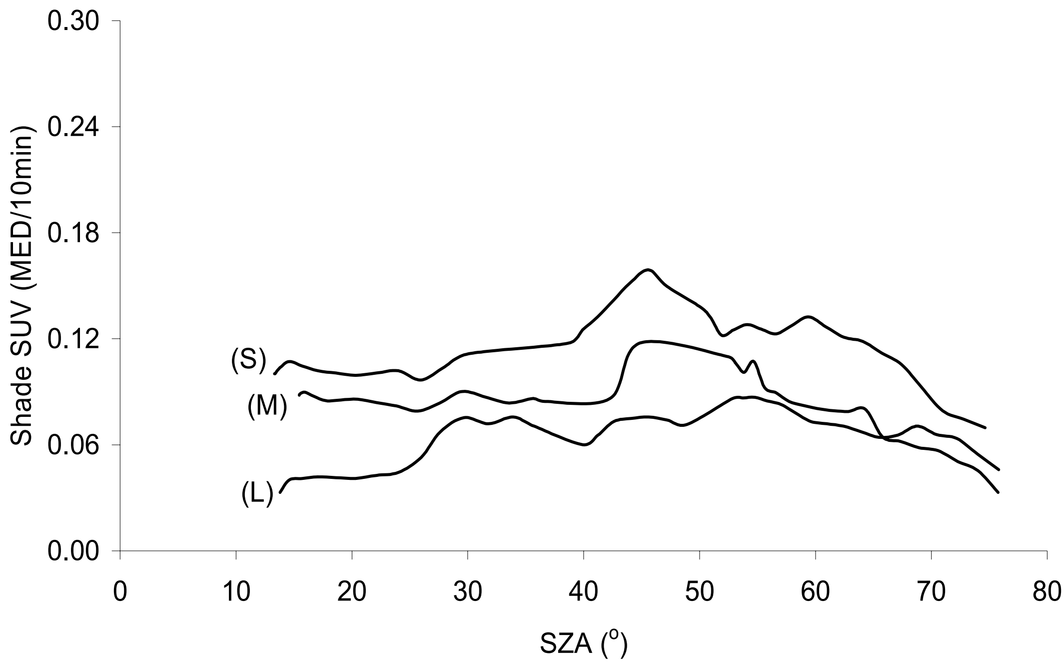


Figure 6.1. Maximum SUV levels observed in the centre of the shade from both the vertical and horizontal measurements for the shade structures small (S), medium (M) and large (L), as a function of SZA.

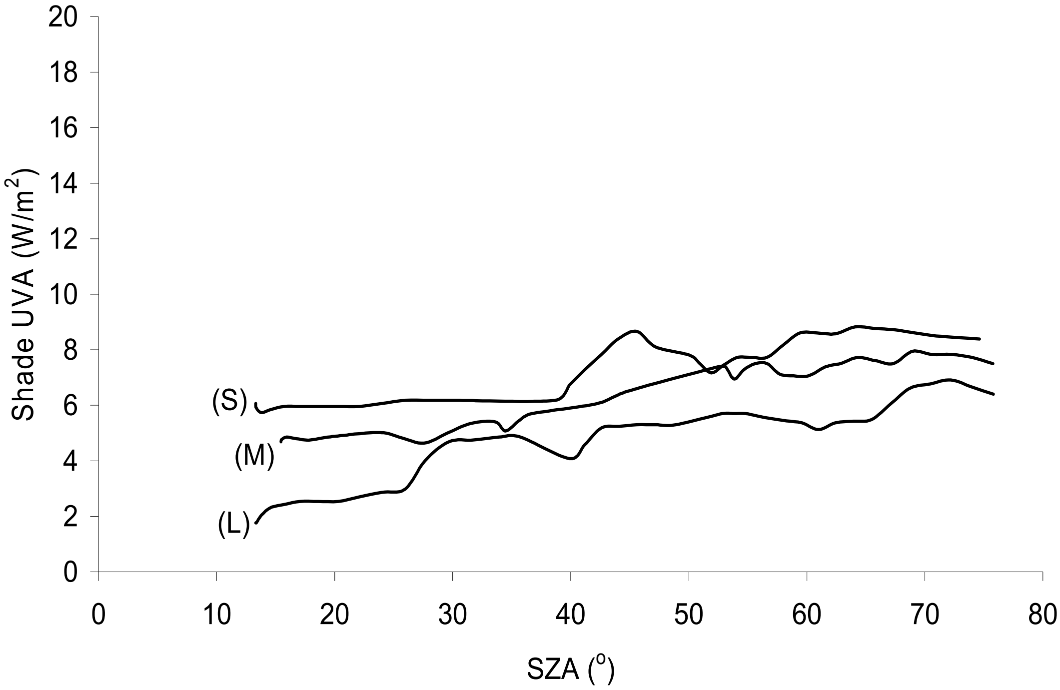


Figure 6.2. Maximum UVA levels observed in the centre of the shade from both the vertical and horizontal measurements for the shade structures small (S), medium (M) and large (L), as a function of SZA.

Figure 6.1 shows the comparison of the levels of SUV in the shade of the three shade structures as a function of SZA for clear skies. For the SZA's of 44^o to 53^o, the erythemal UV beneath the shade structures was at a maximum. The maximum values were 0.16 MED/10 min, 0.12 MED/10 min and 0.09 MED/10 min for the small, medium and large shade structures respectively. At a SZA of approximately 75^o, levels of SUV in the shade were 0.07 MED/10 min, 0.03 MED/10 min and 0.05 MED/10 min for the small, medium and large shade structures respectively. For the peak UV period during summer of approximately 14^o, levels of SUV in the shade were 0.10 MED/10 min, 0.09 MED/10 min and 0.03 MED/10 min for the small, medium and large shade structures respectively. Generally, SUV levels in the shade of the three structures increased as the SZA decreased from approximately 76^o to 45^o before decreasing as the SZA decreased.

Figure 6.2 shows UVA levels in the shade for the three shade structures. UVA levels in the shade showed a general decreasing trend as the SZA decreased. Maximum UVA levels measured beneath the shade structures were 8.8 W/m^2, 7.9 W/m^2 and 6.9 W/m^2 for the small, medium and large shade structures respectively. The lowest UVA levels measured beneath the shade structures were 5.1 W/m^2, 4.6 W/m^2 and 1.8 W/m^2 for the small, medium and large shade structures respectively.

The relative proportion of SUV in the shade of the large shade structure decreases more rapidly than the other shade structures as the SZA decreases. This reduction can be attributed to the larger roof area, compared to the smaller structures, obscuring more of the sky at the smaller SZA's. When comparing SUV to UVA shade ratios (refer to Table 6.1), the levels of SUV are much higher than for UVA because there is less diffuse UVA than SUV and the SUV is more biologically effective in the UVB waveband than the UVA. Consequently, Rayleigh scattering results in increased scattering at the shorter wavelengths associated with the UVB waveband. There is also less difference between the shade structures for the UVA shade ratios. The shade ratio is defined as the UV exposure in the shade divided by the UV exposure in the full sun on a horizontal plane. The RB meter was used to measure full sun SUV on a horizontal plane at least 5 m from the shade structures. This illustrates that roof area has a more important role in decreasing the scattered SUV than the UVA.

Table 6.1. The maximum and minimum observed shade ratios for the three shade structures of small, medium and large.

		Shade Ratios	
		SUV	UVA
Small	Max	0.65	0.42
	Min	0.14	0.12
Medium	Max	0.59	0.41
	Min	0.11	0.09
Large	Max	0.51	0.36
	Min	0.05	0.03

The reduction in SUV for the shade structures is due to the following reasons: the decrease in sky view as the SZA decreased, resulting in diminishing the distance from the centre of the shade to the centre of the shade structure; and there is less scattered UVB as SZA decreases and so less SUV in the shade.

6.3 UV Protection Factors

The protective ability of a shade structure is illustrated through its ultraviolet protection factor or UPF. The UPF is calculated according to the following equation:

$$UPF = \frac{UV_{FS}}{UV_S} \qquad (6.1)$$

where UV_{FS} is the full sun UV irradiance and UV_S is the UV irradiance in the shade. The ultraviolet protection factors for each shade structure and clear sky conditions are plotted as a function of SZA in Figure 6.3. Maximum and minimum UPF's are provided in Table 6.2. An obvious decrease in UPF occurs as the SZA increases for each of the shade structures; this decrease takes place due to the increase in the relative proportion of the scattered UV as a result of the larger SZA. However, such a decrease does not necessarily mean an increase in UV levels beneath the shade structures. As Figure 6.1 shows, the highest levels of SUV measured under the large shade structure were around a SZA of between 44^o to 53^o. The increase in UPF for the large shade structure, at the smaller SZA's, can be attributed to the fact that the centre of the shade received more protection from the roof (due to the decreased amount of sky view from the shade being closer to the centre of the shade structure) when compared to the other shade structures. For clear sky days and SZA range of 13^o to 76^o the relationships are:

Small Shade Structure

$$UPF_S = 1.4\text{x}10^{-3}(SZA)^2 - 0.2(SZA) + 10.2 \quad (6.2)$$

Medium Shade Structure

$$UPF_M = 1.6\text{x}10^{-3}(SZA)^2 - 0.3(SZA) + 14.7 \quad (6.3)$$

Large Shade Structure

$$UPF_L = -4\text{x}10^{-5}(SZA)^3 + 1.1\text{x}10^{-2}(SZA)^2 - 0.95(SZA) + 30.1 \quad (6.4)$$

R^2 for equations 6.2, 6.3 and 6.4 are 0.98, 0.95 and 0.99, respectively. A cubic polynomial is used for the large shade structure, as it provides a better fit for the larger SZA. Equations 6.2 to 6.4 were calculated assuming isotropic sky radiance.

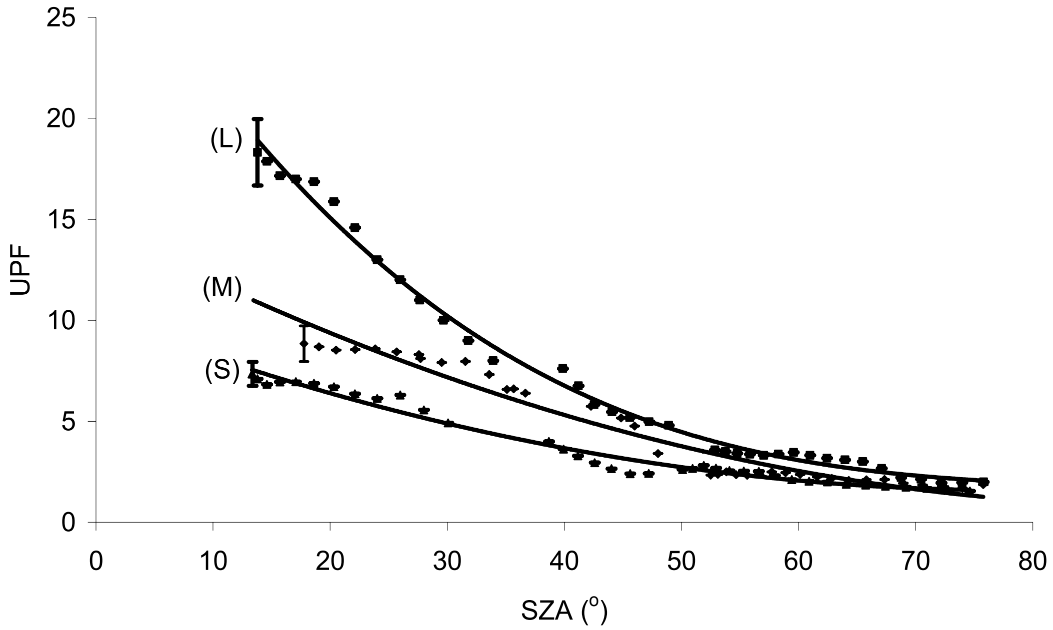


Figure 6.3. Ultraviolet protection factors for each shade structure, small (S), medium (M) and large (L), as a function of SZA. The error bars indicate, for one data point as an example, the combined errors associated with the UV in the shade and the full sun UV measurements for the maximum SZA.

Table 6.2. Maximum and minimum protection factors for the three shade structures.

	UPF	
	Max	Min
Small	7.3	1.5
Medium	8.8	1.7
Large	18.3	2.0

6.4 Diffuse UV and UV in the Shade

Figure 6.4 shows the relationship between the diffuse SUV in the sun as measured by the roof-mounted radiometer and the scattered SUV in the shade on a horizontal plane measured for each of the shade structures. From this plot the relationships between the diffuse SUV in the full sun and the scattered UV beneath these three shade structures can be obtained for the range of SZA's of 13° to 76°. For clear sky days and SZA range of 13° to 76° the relationships are:

Small Shade Structure

$$SUV_s = 17679(SUV_d)^4 - 4083.3(SUV_d)^3 + 318.36(SUV_d)^2 - 9.422(SUV_d) + 0.123 \quad (6.5)$$

Medium Shade Structure

$$SUV_s = -1180(SUV_d)^4 + 512(SUV_d)^3 - 71.8(SUV_d)^2 + 3.8(SUV_d) - 0.0372 \quad (6.6)$$

Large Shade Structure

$$SUV_s = -3591(SUV_d)^4 + 1038.2(SUV_d)^3 - 113.5(SUV_d)^2 + 5.223(SUV_d) - 0.058 \quad (6.7)$$

where SUV_d is the diffuse UV and SUV_s is the scattered UV in the shade of the shade structures on a horizontal plane. The coefficient of determination for equations 6.5, 6.6 and 6.7 are 0.98, 0.89 and 0.96, respectively. From the relationships obtained for each shade structure, an additional set of measurements were conducted in the shade of the shade structures and compared against the regression curves for a range of SZA from 11° to 66°. For the small, medium and large shade structures, variation between the field measurements and those of the regression curves was up to approximately 11%, 5% and 11%, respectively.

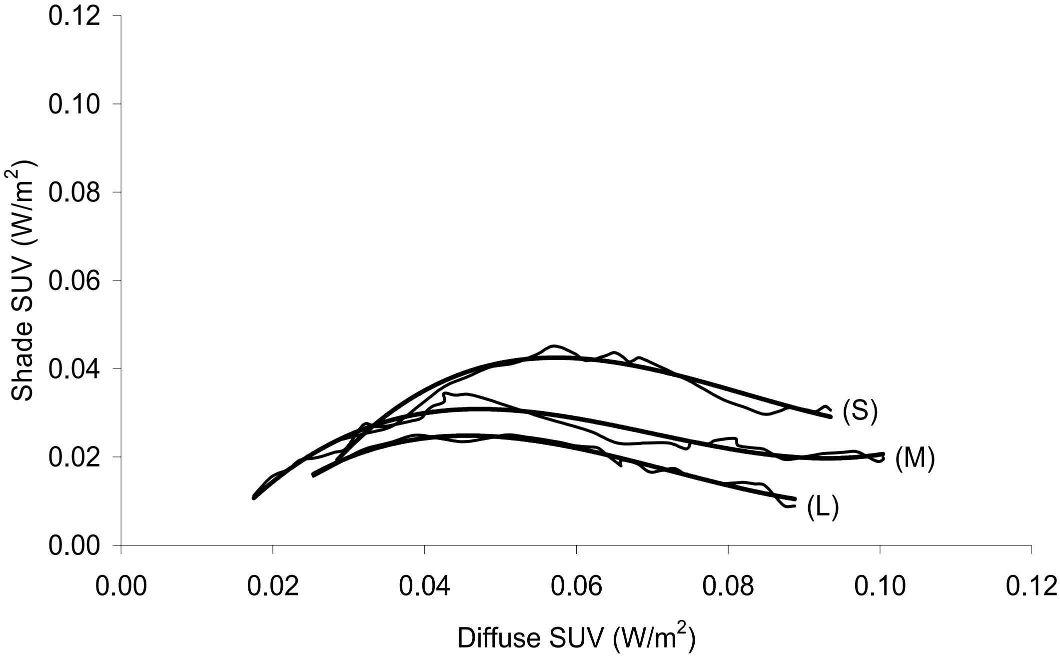


Figure 6.4. Scattered SUV in the shade of the shade structures compared with the diffuse SUV measurements.

6.5 Visible Radiation in the Shade

Figure 6.5 shows visible intensity levels in full sun and in the shade of the three shade structures. Visible intensity levels in full sun showed an obvious decreasing trend for an increasing SZA, whereas the measurements in the shade showed no distinct trend for a changing SZA. Full sun intensity levels ranged from approximately 140000 lux at a SZA of 14^o to 50000 lux for a SZA of 75^o. For a small SZA of approximately 14^o, visible intensity levels measured beneath the shade structures were in the order of 10000 lux, 7900 lux and 8000 lux for the small, medium and large shade structures respectively. For a larger SZA of approximately 75^o, visible intensity levels measured beneath the shade structures were in the order of 8600 lux, 7900 lux and 7900 lux for the small, medium and large shade structures respectively. These results show that visible intensity levels in the shade are not dependent on SZA because the diffuse fraction is small and provides no indication of the UV irradiances in the shade.

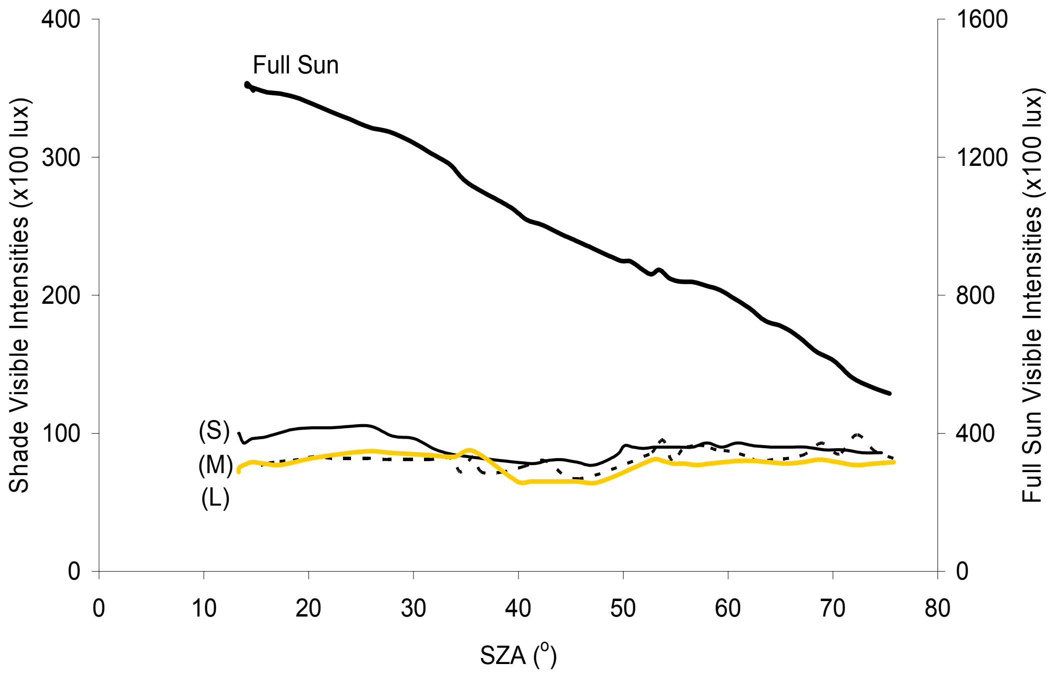


Figure 6.5. Full sun and shade visible illuminance as a function of SZA for the three shade structures, small (S), medium (M) and large (L).

6.6 Structural Modifications and Facial Dosimetry

The next step in the research, now that the UV beneath the shade structures had been quantified, was to structurally modify a shade structure to reduce scattered UV levels beneath the structure. The side openings of a shade structure have a direct influence on UV levels in the shade and more importantly where the shade falls during the course of the day and the year. As seen in Figure 4.15, the shade from the shade structures does not always fall where the benches and seats are positioned.

Therefore, two types of side-on protection, namely polycarbonate (PC) sheeting and vegetation, were tested in order to bring the shade, created by the structure, back under the shade structure for all SZA. Three types of PC sheeting were investigated (manufacturer, SolarLite, Australia), namely clear, grey and bronze.

6.6.1 Anatomical Facial Exposures

Anatomical facial exposures for the use and non-use of PC sheeting are shown in Tables 6.3 and 6.4 for winter and summer for an exposure period of 3 hours. Maximum UV exposures during winter for the non-use of PC sheeting were 0.30 MED and 0.27 MED for the neck and lips respectively. The use of the PC sheeting reduced the exposure to the neck by 33%, 27% and 40% for the bronze, grey and clear tints respectively. Exposure to the lips was reduced by 26%, 22% and 41% for the bronze, grey and clear tints respectively. For summer, maximum UV exposures for the non-use of PC sheeting were 1.07 MED and 0.99 MED for the chin and neck respectively. The use of PC sheeting reduced exposure to the chin by 51%, 67% and 40% for the bronze, grey and clear tints respectively. In comparison, the PC sheeting reduced exposure to the neck by 45%, 58% and 45% for the bronze, grey and clear tints respectively. Full sun exposures to the eyes ranged from 1.12 MED to 2.58 MED for winter and summer respectively. The use of the clear tint PC sheeting reduced exposures to the eyes by approximately 87% for both winter and summer, whereas the bronze and clear tints reduced exposure by 83% for winter and 88% and 91% for summer respectively.

Table 6.3. Average anatomical facial exposures beneath the model shade structure for different types of PC sheeting for winter.

	Winter (MED)				
Dosimeter Position	No PC	Bronze	Grey	Clear	Full Sun
top of head	0.05 (0.00)	0.05 (0.01)	0.03 (0.00)	0.02 (0.02)	3.75 (0.37)
forehead	0.20 (0.06)	0.16 (0.04)	0.10 (0.00)	0.15 (0.04)	2.29 (0.28)
bridge of nose	0.23 (0.06)	0.13 (0.03)	0.21 (0.01)	0.14 (0.03)	2.54 (0.55)
lips	0.27 (0.03)	0.20 (0.02)	0.21 (0.02)	0.16 (0.02)	1.28 (0.06)
chin	0.17 (0.04)	0.10 (0.00)	0.14 (0.03)	0.17 (0.01)	0.52 (0.17)
cheeks	0.16 (0.04)	0.12 (0.01)	0.16 (0.03)	0.14 (0.00)	1.13 (0.05)
ears	0.21 (0.08)	0.13 (0.02)	0.21 (0.02)	0.16 (0.01)	1.26 (0.39)
neck	0.30 (0.08)	0.20 (0.02)	0.22 (0.06)	0.18 (0.04)	1.95 (0.25)
back of head	0.21 (0.05)	0.12 (0.05)	0.19 (0.02)	0.17 (0.03)	1.50 (0.25)
eyes	0.18 (0.03)	0.18 (0.00)	0.18 (0.04)	0.14 (0.04)	1.12 (0.10)

Table 6.4. Average anatomical facial exposures beneath the model shade structure for different types of PC sheeting for summer.

	Summer (MED)				
Dosimeter Position	No PC	Bronze	Grey	Clear	Full Sun
top of head	0.06 (0.00)	0.04 (0.00)	0.02 (0.00)	0.03 (0.00)	13.06 (1.11)
forehead	0.59 (0.00)	0.28 (0.01)	0.19 (0.00)	0.30 (0.00)	7.23 (0.56)
bridge of nose	0.71 (0.01)	0.28 (0.01)	0.43 (0.02)	0.33 (0.00)	9.24 (0.70)
lips	0.88 (0.00)	0.43 (0.00)	0.59 (0.00)	0.49 (0.00)	3.21 (0.48)
chin	1.07 (0.02)	0.52 (0.01)	0.35 (0.01)	0.64 (0.01)	2.50 (0.39)
cheeks	0.75 (0.00)	0.40 (0.02)	0.37 (0.06)	0.39 (0.01)	3.00 (0.12)
ears	0.68 (0.04)	0.37 (0.04)	0.37 (0.06)	0.40 (0.04)	2.59 (0.39)
neck	0.99 (0.05)	0.54 (0.04)	0.42 (0.14)	0.54 (0.06)	3.50 (1.00)
back of head	0.78 (0.01)	0.35 (0.00)	0.18 (0.00)	0.33 (0.00)	3.53 (0.47)
eyes	0.62 (0.04)	0.30 (0.03)	0.23 (0.03)	0.36 (0.01)	2.58 (0.26)

The anatomical facial exposure shade ratios for winter and summer are shown in Tables 6.5 and 6.6 for the cases of no PC and each type of PC. The shade ratios, UV_{ESR}, were calculated according to the following equation:

$$UV_{ESR} = \frac{UV_S}{UV_H} \times 100\% \qquad (6.8)$$

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. 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 measurements in full sun 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.

Table 6.5. Anatomical facial distribution of shade ratios based on the average facial exposure beneath the model shade structure for winter.

	Winter (Shade Ratios)			
Dosimeter Position	No PC	Bronze	Grey	Clear
top of head	1.4	1.2	0.7	0.6
forehead	5.6	3.7	2.5	4.5
bridge of nose	6.4	3.1	5.6	4.2
lips	7.6	4.6	5.4	4.8
chin	4.8	2.5	3.5	5.1
cheeks	4.3	2.9	4.2	4.2
ears	5.7	3.0	5.5	4.8
neck	8.5	4.7	5.7	5.3
back of head	5.9	2.9	4.9	5.1
eyes	5.0	4.2	4.5	4.0

Table 6.6. Anatomical facial distribution of shade ratios based on the average facial exposure beneath the model shade structure for summer.

	Summer (Shade Ratios)			
Dosimeter Position	No PC	Bronze	Grey	Clear
top of head	0.4	0.3	0.2	0.2
forehead	4.0	2.2	1.5	2.4
bridge of nose	4.8	2.2	3.5	2.7
lips	6.0	3.3	4.8	4.0
chin	7.3	4.0	2.8	5.2
cheeks	5.1	3.0	3.0	3.2
ears	4.6	2.8	3.0	3.2
neck	6.7	4.1	3.4	4.4
back of head	5.3	2.7	1.5	2.7
eyes	4.2	2.3	1.9	2.9

The ultraviolet protection factors for the scale model with and without PC sheeting are provided in Table 6.7. The UPF was calculated using the maximum anatomical facial exposure in the shade and comparing it to a full sun horizontal plane measurement. As expected, the non-use of PC sheeting provided the lowest protection factors of 12.5 and 12.2 for winter and summer respectively. The highest protection factor for winter was 20.8 with the use of the clear tint PC sheeting, whereas, the bronze tint provided the highest protection factor of 24.2 for summer. The uncertainty of polysulphone dosimeters is of the order of approximately 10%. Therefore, the UPFs calculated do not show a significant difference when comparing the different types of PC sheeting. However, the addition of side-on protection does significantly increase the protection factor of a shade structure.

Table 6.7. Ultraviolet protection factors for the use and non use of PC sheeting.

	UPF			
	No PC	Bronze	Grey	Clear
winter	12.5	18.8	17.0	20.8
summer	12.2	24.2	22.1	20.4

6.6.2 Surrounding Plant Life

As can be seen in Figure 6.6 and Table 6.8, 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 6.6 and 6.7, 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.

The UPF's for the shade structures with and without surrounding vegetation are provided in Figure 6.8 and Table 6.9. The shade structure with no surrounding vegetation provided the lowest protection factors for a changing SZA. The highest protection factors were observed for the shade structure with vegetation to the north-eastern, northern, north-western and western directions. This shows that the addition of side-on protection can improve the protective ability of a shade structure.

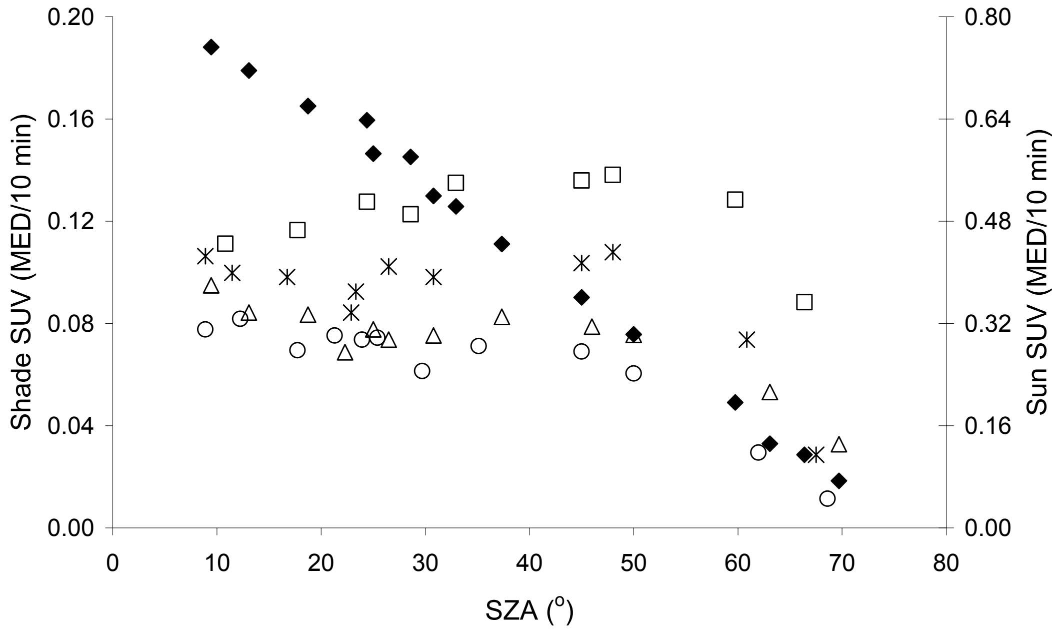


Figure 6.6. Maximum SUV exposures observed from the horizontal and vertical planes beneath the four shade structures, (a) □ ,(b) Δ, (c) O, (d) ∗, compared to full sun (◆) (right axis).

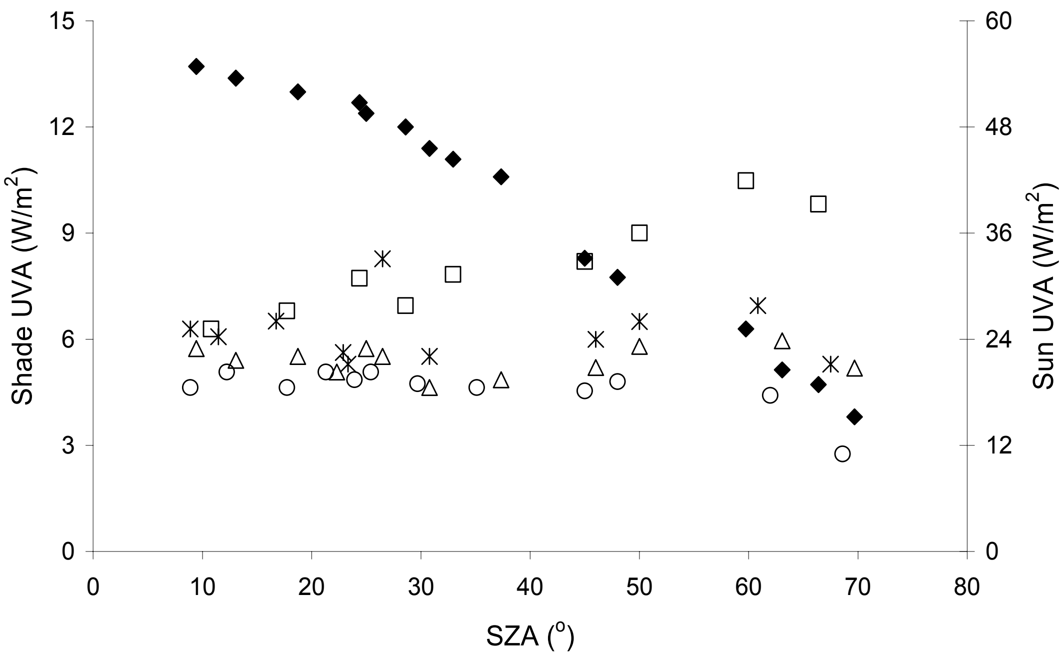


Figure 6.7. Maximum UVA exposures observed from the horizontal and vertical planes beneath the four shade structures, (a) □ ,(b) Δ, (c) O, (d) ∗, compared to full sun (◆) (right axis).

Table 6.8. Summary of the maximum and minimum erythemal UV exposures observed in the shade of the four shade structures with varying degrees of surrounding vegetation.

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

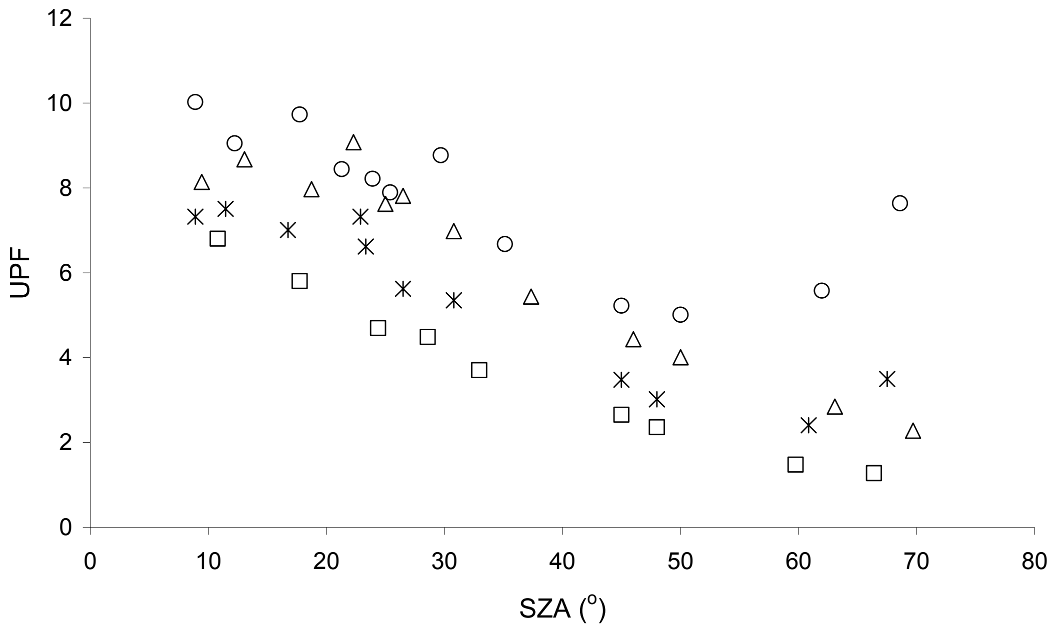


Figure 6.8. Ultraviolet protection factors for erythemal UV for each shade structure (a) □ ,(b) Δ, (c) O, (d) ∗ as a function of SZA.

Table 6.9. Maximum and minimum ultraviolet protection factors for the four shade structures with varying degrees of surrounding vegetation.

	UPF	
	Max	Min
a □	6.8	1.3
b Δ	9.0	2.3
c ○	10.0	5.0
d ∗	7.5	2.4

6.7 Chapter Discussion

From this research it can be concluded that these specific shade structures are inadequate for providing the public enough protection against damaging UV radiation for changing SZA. Even in winter the erythemal UV in full sun can be more than adequate to induce erythema, with levels reaching approximately 2.5 MED/Hr during the middle of the day. This research provides data on the scattered UV incident from the vertical and horizontal planes and for the SZA observed throughout an entire year. These angular measurements are crucial in showing that research into the effects of side-on protection is essential. The ultraviolet protection factors of the three public shade structures ranged from 1.5 for the larger SZA of approximately 76^{o} and up to 18 for the smaller SZA of approximately 13^{o}. UPF's are analogous to SPF's (Sun Protection Factor's), the larger the better. For the shade structures employed in this research a relationship between the diffuse UV and the UV in the shade has been provided for clear skies and SZA's of 13^{o} to 76^{o}. This allows the evaluation of the UV in the shade of these shade structures if the diffuse UV can be measured or modelled.

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. Unfortunately no such measurements were able to be conducted for vegetation situated on the eastern sides of a shade structure due to the lack of an available site. However, vegetation situated on eastern sides of a shade structure would also be effective at decreasing scattered UV in the shade.

CHAPTER 7

CONCLUSIONS

7.1 UV and Shade Structures

This research shows that some public shade structures are inadequate for providing the public enough protection against damaging UV radiation for a changing SZA. Figure 4.15 shows the shade structures used for this research, and how ineffective they are for shading the seats and benches for larger solar zenith angles. Parsons et al (1998) states that a protection factor of at least 15 (93% reduction in UV) is desirable for outdoor activities. Calculated protection factors of the shade structures used in this research ranged from 1.5 to 18 for a decreasing SZA of 76^o to 13^o. The large shade structure provided protection factors of approximately 2 for a SZA of 76^o and 15+ (maximum 18) for a SZA less than approximately 25^o. However, the small and medium sized shade structures did not provide a protection factor greater than 10 for the same smaller SZA. A relationship between SZA and the protection factors offered by the shade structures throughout the year is provided in chapter 6.

Although peak SUV levels outside the shade structures were observed during the smaller SZA for summer, the highest SUV levels in the shade were seen during the SZA related to late autumn through to early spring. For a SZA of approximately 45^o, the period spent in the shade before receiving 1 MED ranged from 60 minutes to 80 minutes for the small and medium shade structures respectively. For a SZA of approximately 54^o, time spent in the shade before receiving 1 MED was 110 minutes for the large shade structure. This occurred mainly due to the angle of the sun causing the shade to be outside the shade structure, therefore increasing the amount of sky view and incident scattered UV for the person sitting in the shade created by the shade structure.

For the shade structures employed in this research a relationship between the diffuse SUV in the open (ambient diffuse SUV) and the SUV in the shade has been provided in chapter 4 for clear skies and a changing SZA from 13^{o} to 76^{o}. This is a significant innovation as it allows the evaluation of the UV in the shade of these shade structures if the ambient diffuse SUV can be measured or modelled. The measurements provided in this research are based on the scattered UV incident from the vertical and horizontal planes and for the SZA observed throughout an entire year. These angular measurements and changing SZA are crucial in showing that research into the effects of side-on protection is essential.

The entire shade environment needs to be carefully considered before a shade structure is constructed. The size and orientation of 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. The next stage in this research was to calculate the reduction in personal UV exposure by modifying a shade structure to include some form of side-on protection. 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, namely polycarbonate sheeting and vegetation. Measurements conducted in the shade of a scale model shade structure during summer and winter showed that scattered UV levels could be more than halved by adding polycarbonate sheeting to the northern and north-eastern sides of the shade structure compared to measurements without polycarbonate sheeting. Measurements conducted in the shade of the shade structures with varying amounts of evergreen vegetation covering different sides, showed that specific positioning of the vegetation could significantly reduce UV levels in the shade by up to 89% for certain times of the day.

Polycarbonate sheeting was found to be useful for locations and SZA's where winter warmth and lighting 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. This is described in more detail in section 7.4.

When constructing shade structures, careful consideration must be given to these findings because, even though summer has the highest UV levels in the full sun, winter has the highest relative proportion of scattered UV in the shade due to the increased scattering resulting from the longer path of the solar UV through the atmosphere. The highest levels of scattered SUV (see Figure 6.1 for absolute values) in the shade were observed for the SZA most commonly attributed to the middle of the day for late autumn through to early spring. However, the highest UVA levels were observed predominantly during winter.

Shade is certainly important as a UV minimisation strategy. However, shade alone does not provide enough protection from some biologically damaging UV. Even though the UV transmission through the materials employed on the roof of the structures may be very low, it is the construction of the entire shade setting that determines the exposure beneath that structure. Shade structures that have trees, shrubs or buildings in close proximity generally have lower levels of UV in the shade than those having no such surrounding objects.

During a winter at a sub-tropical latitude in south east Queensland, full sun UV radiation can reach levels of approximately a third or more of that registered in the middle of the day during summer. Therefore, it is necessary for people who live in similar latitudes to minimise UV exposure under all climatic conditions, throughout the year. Although the protection factors for the three shade structures are insufficient as a sole UV protection strategy, it is still recommended to employ shade as a UV minimisation strategy when outdoors. However, additional sun protection strategies such as hats, appropriate sunglasses, clothing and sunscreen should still be employed, even if seeking shade for an extended period of time during the winter months. Possible changes for shade creation policies are discussed in greater detail in section 7.3.

7.2 Diffuse SUV

A pivotal part of this research was to quantify the ambient diffuse SUV for varying seasons and atmospheric conditions. For this, a shadow band was designed and fabricated during this research at the University of Southern Queensland. The characterisation of the diffuse SUV meter setup is detailed in section 4.2.1.2.

This is the first known research to report on the effects that changing atmospheric ozone concentrations have on diffuse SUV levels for a sub-tropical, southern hemisphere site. From this research, it can be concluded that decreases in atmospheric ozone concentrations have an increasing effect on diffuse SUV irradiances. However, the increasing effect is lower for the diffuse SUV than global

SUV. The observed increase in diffuse SUV for decreasing ozone levels exemplifies the need to reduce exposures to diffuse SUV all year round. This is important in the design of outdoor shade structures and in the use of these structures and other natural forms of shade provided by vegetation.

7.3 National Health Priority Policy

As discussed in Chapter 3 section 3.4, one goal of the National Cancer Prevention Policy is to improve the provision of shade and shade creation. The research presented in this thesis significantly increases the level of quantitative scientific knowledge on shade structures and UV levels beneath and around these structures. This research also helps to address outcome 7.13 of the Queensland Skin Cancer Prevention Strategic Plan 2001 - 2005 to "Conduct research to determine 'what is effective shade?'". What needs to follow on from the research in this project is the appropriate dissemination of the recommendations to individuals and groups, from day care centres to schools to local government. The recommendations based on the research in this project are detailed in the following sections.

7.3.1 Possible Changes to Public Health Policy

In the middle of the day for south east Queensland, full sun UV radiation can reach levels of approximately 2.5 MED/hr during winter and over 8 MED/hr during summer. Therefore, it is necessary for people who live in similar latitudes to minimise UV exposure under all climatic conditions, throughout the year. From this research it can be concluded that shade structures without some form of side-on protection are inadequate at providing the public shelter from damaging UV radiation. Improving shade structures that are already in place is not a difficult task, it is simply a matter of having a better understanding of the way UV radiation interacts with the earths atmosphere and what can be done to reduce exposure to this radiation. Based on the research from this project, adequacies and inadequacies of shade structures that are already in place are discussed in more detail in section 7.4.

7.4 Changes to Public Areas

The positioning of the shade structure in respect to full sun activities is of key importance particularly where these activities involve infants and children. The following sections provide an indication of good shade structures and also possible changes to shade areas that can be implemented. The following figures are examples of shade environments located in the Toowoomba area.

7.4.1 Early Childhood Centres and Pre-Schools

Infrequent over exposure and cumulative exposure are both important risk factors in the development of skin cancer. Therefore, minimizing the exposure to solar radiation during childhood may have significant implications for cancer rates later in life. Having appropriate shade environments at early childhood centres and pre-schools is vital in limiting the levels of detrimental solar UV radiation children are exposed to. Figure 7.1 to 7.3 show examples of shaded play ground areas at a local pre-school. The main concern with the shade structures in Figures 7.1 and 7.2 are that the amount of over hang needs to be increased by at least 1 m to account for the SZA observed during winter.

Figure 7.3 shows a well placed piece of playground equipment utilizing trees as a form of natural shade. Wide spreading, dense canopied evergreen trees are an excellent way of providing natural shade. Shade creation guidelines such as Greenwood (2000) state that using deciduous trees to create shade is an appropriate option for allowing warmth and light into the play area during winter. However, this is inappropriate guidance as solar erythemal UV radiation at a sub-tropical and lower latitudes can still be hazardous during the winter months (Turnbull, 2003). Research by Turnbull et al, (2003) has shown ambient erythemal UV levels of up to 2.5 MED/h in the middle of the day during winter.

Figure 7.4 shows a section of a playground area of an early childhood centre. While there is some shade provided, it is not adequate as children using the equipment will not consistently stay underneath the small amount of shade that is provided. A large shade structure as shown in Figure 7.1 would be more beneficial to have covering the equipment in Figure 7.4, as well as appropriately placed trees or shrubs for side-on protection.


Figure 7.1. Pre-school play ground equipment.


Figure 7.2. Pre-school sand pit.


Figure 7.3. Pre-school play ground equipment.


Figure 7.4. Sandpit and play ground equipment at an early childhood centre.

7.4.2 Schools

Schools are also of particular importance for reducing solar UV exposure, as students attend school five days per week for a substantial part of the year encompassing all seasons. The provision of shade is important for times when students are outside, for example lunch time and playing sport. Figure 7.5 shows a specifically built shade structure with shade cloth as the roofing material for use by students during the lunch time break. The major concern with shade structures like that shown in Figures 7.1, 7.2 and 7.5 is the transmission qualities of the shading fabric. The looser the weave, the more solar UV radiation can pass through and cause problems for those sitting beneath it. The provision of shade does have other unfortunate drawbacks; for example, Figure 7.6 shows school ground play equipment that originally had a large shade cloth shade structure covering it. This shade cloth was vandalised and had to be removed due to significant damage. Due to the cost of the shade cover, it was unable to be replaced.

Figure 7.5. Shade provided for students during their lunch break.

Figure 7.6. Playground equipment without shade protection due to vandalism.

7.4.3 Parks and Recreational Areas

Use of outdoor environments is very popular in Australia, with people using these areas throughout the day and year. People will often use outdoors areas for relaxing, eating at restaurants or having barbeques. Therefore, it is important to offer the most effective shade possible to people using these areas. Figure 7.7 shows a common style of shade structure found in parks located in the Toowoomba area. The inadequacy of this shade structure and play area is that the shade produced by the structure is not always beneath the shade structure and the play area offers no form of shade at all to those using it. Adequate side-on protection is needed for the shade structure and a large shade covering for the play area (similar to that shown in Figure 7.1). Figure 7.8 shows an outdoor eating setting with a shade umbrella. As can be seen from this, the shade umbrella offers no protection at all for those sitting at the table. The shade umbrella would have to be enormous to offer adequate protection throughout the day.


Figure 7.7. Shade structure located next to playground equipment.


Figure 7.8. Outdoor eating area.

7.4.4 Swimming Pools

Pools are a common place for people to be during peak exposure periods, simply because they want to cool off in the water or gain a tan. Schools often use pools for teaching students how to swim and for swimming carnivals. Figure 7.9 shows a pool with a grandstand that would be very useful for swimming lessons and swimming carnivals held in the afternoon, as the grandstand is located on the western side of the pool. However, the gap in the side of the structure behind and above the seats needs to be filled in with a UV impenetrable material. Significant changes to when schools use their pools is slowly taking shape through lobbying by a Brisbane dermatologist and advice based on this research.

Figure 7.9. School swimming pool with shaded grandstand.

7.4.5 Sports Fields

Sports fields are important areas for shade usage, as they are generally used throughout the year by both players and spectators. Figures 7.10 and 7.11 shows shade structures that have been built for use at sports fields in Toowoomba. The most common problem with these shade structures is that they lack side-on protection. This is evident from the shade produced by the shade structure being away from where the benches and seats are. These problems can be reduced by the correct positioning of the shade structures for the type of sporting field and also by using side-on protection. For example, when people are playing 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. This significantly reduces the direct component of solar UV with respect to the people in the shade structure. Conversely, for afternoon sport the shade structure with appropriate side-on protection needs to be positioned on the western side of the field. This side-on protection can be attained by natural shading, as shown in Figure 7.12.

Figure 7.10. Large shade structure located at a sports field.

Figure 7.11. Small shade structure located at a sports field.


Figure 7.12. A sports field shade structure with natural side-on protection.

7.5 Problems with Shade Design and Creation

The design and creation of shade structures is limited by a number of factors that include cost, safety and council building requirements. The cost of shade structures is a major concern as most schools and child care centres cannot afford large complex structures that would provide better UV protection. Therefore, these organisations erect smaller less efficient shade structures. Also, each council has different planning guidelines. However, most have a 10 m^2 limitation before a building permit is required. This limits the designing of a shade structure that would be more beneficial. A simple 10 m^2 shade sail costing $500 would triple in price if one extra square metre were added due to the need for a building permit (personal communication, 2005). The safety of those using a shade structure also causes difficulties in design of shade structures. There are certain heights that structures must be in order to clear the reach of children, for example, if the shade structure is placed over play equipment that is 1 m high then an allowance must be made for this. Most regulations specify 1.5 m from any play equipment, fence, or tree and an entry height of no less than 2.2 m (personal communication, 2005). Possible ways around this is for councils, governments and other organisations to offer better funding opportunities and for councils to relax building limitations for groups such as childcare centres and schools. A brief list of current funding opportunities for shade creation is provided in Appendix C.

7.6 Shade Sails

The Queensland Cancer Fund (QCF) describes shade sails as: "…usually made from shade cloth and resemble the sails of a boat and often large open spaces exist between the sails which allow a lot of UVR through. Shade sails are often an expensive option and do not adequately cast shade over the desired area." (http://www.qldcancer.com.au/). Figures 7.13 and 7.14 show how shade sails have been used for areas such as sports fields and play equipment. Although the QCF states that shade sails are inadequate at providing shade, the Under Cover guidelines advocate using shade sails as a means of providing an aesthetically pleasing shade environment for areas where children play, for example, early childhood centres, schools and beach areas. The Under Cover guidelines also state that sail designs seem to attract the most vandalism. This begs the question: why use shade sails at all? This discrepancy between the QCF and the shade guidelines shows that the Under Cover guidelines need to be updated and improved for providing the lay person and group with the information needed to create the most effective shade for reducing personal UV exposure.


Figure 7.13. Shade sails at a sports field.

Figure 7.14. Shade sail used to cover play equipment.

7.6 Summary of Conclusions

The research in this project has quantified the solar UV environment beneath and surrounding local council public shade structures. The effects of changing seasons, atmospheric conditions, structural modifications and surrounding plant life on diffuse UV have also been quantified. Strategies to improve shade structures so as to significantly reduce the levels of diffuse UV reaching the human body in the shade have also been developed from this research.

When constructing shade structures, careful consideration must be given to the findings based on this research because, even though summer has the highest UV levels in the full sun, winter has the highest relative proportion of scattered UV in the shade due to the increased scattering resulting from the longer path of the solar UV through the atmosphere. Shade is certainly essential as a UV minimisation strategy as people do not always have access to sunscreen or protective clothing when it is needed. However, shade alone does not always provide enough protection from some biologically damaging UV. Even though the UV transmission through the materials employed on the roof of the structures may be very low, it is the construction of the entire shade setting that determines the exposure beneath that structure. Shade structures that have trees and/or shrubs in close proximity will have lower levels of UV in the shade than those with no surrounding protection.

There are numerous ways of preventing sunburn and other deleterious effects due to excess sun exposure. Prevention behaviours include simple things such as: wearing hats, appropriate clothing, sunglasses, sunscreens and seeking shade. These prevention behaviours need to be used in conjunction with one another; otherwise the full sun protective affect will not occur. Updated shade guidelines based on the findings of this research, more funding for shade creation grants (see Appendix C), relaxing council regulations for some groups and ongoing public education that targets specific groups and settings may contribute to an adoption of appropriate sun protective behaviours and an eventual decline in the deleterious effects caused by sun exposure.

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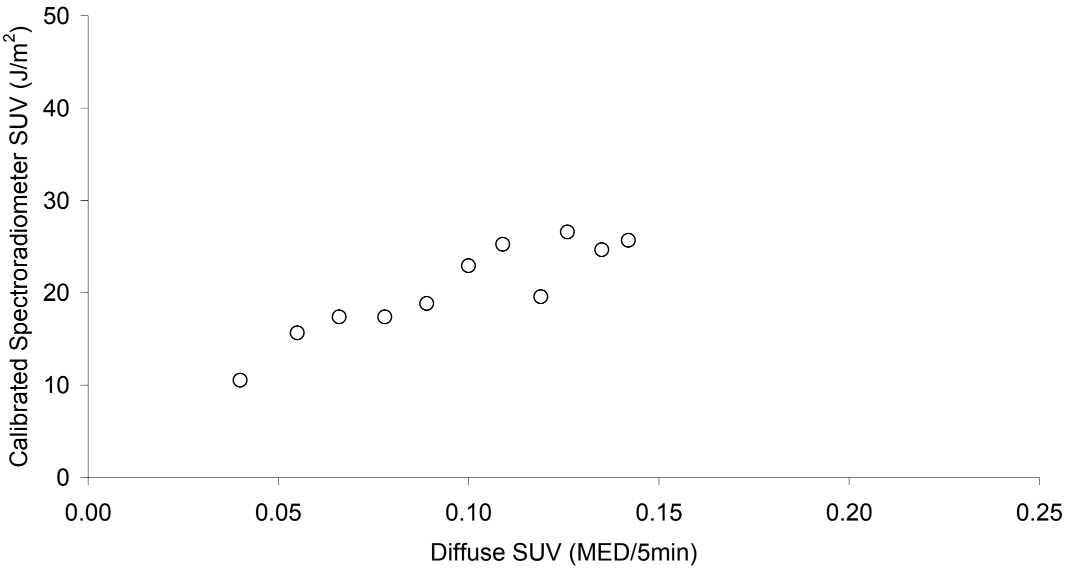
Appendix A

Calibration Charts

(a)



(b)

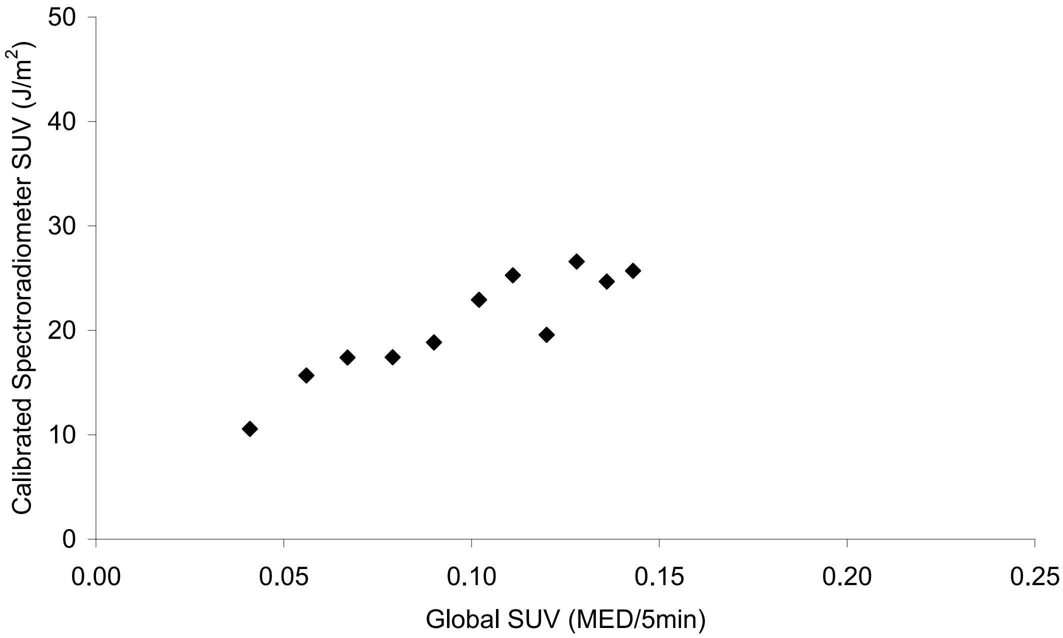


Figure A.1. Calibration of diffuse (a) and global (b) SUV meters for winter 2002.

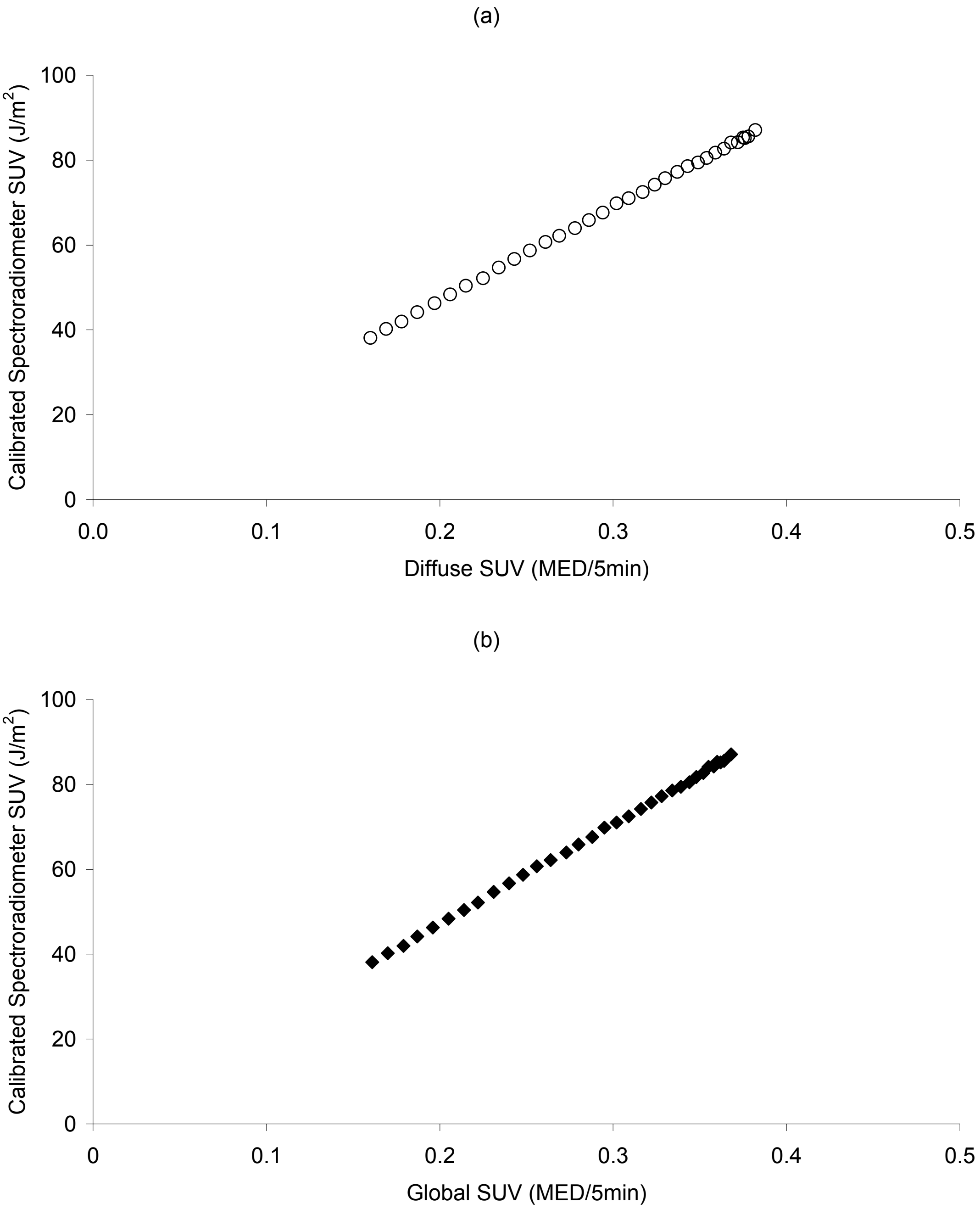


Figure A.2. Calibration of diffuse (a) and global (b) SUV meters for summer 2002/2003.

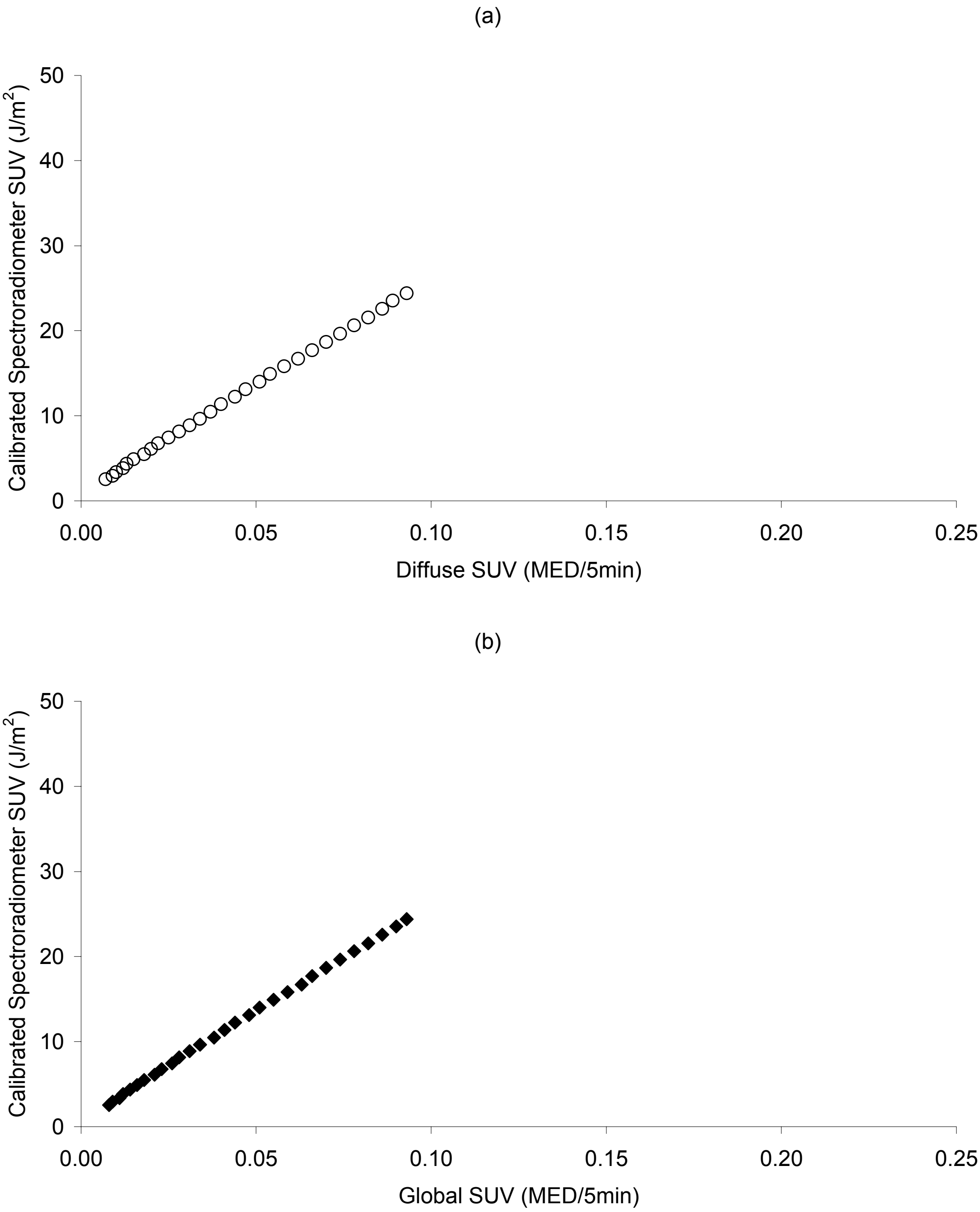


Figure A.3. Calibration of diffuse (a) and global (b) SUV meters for winter 2003.

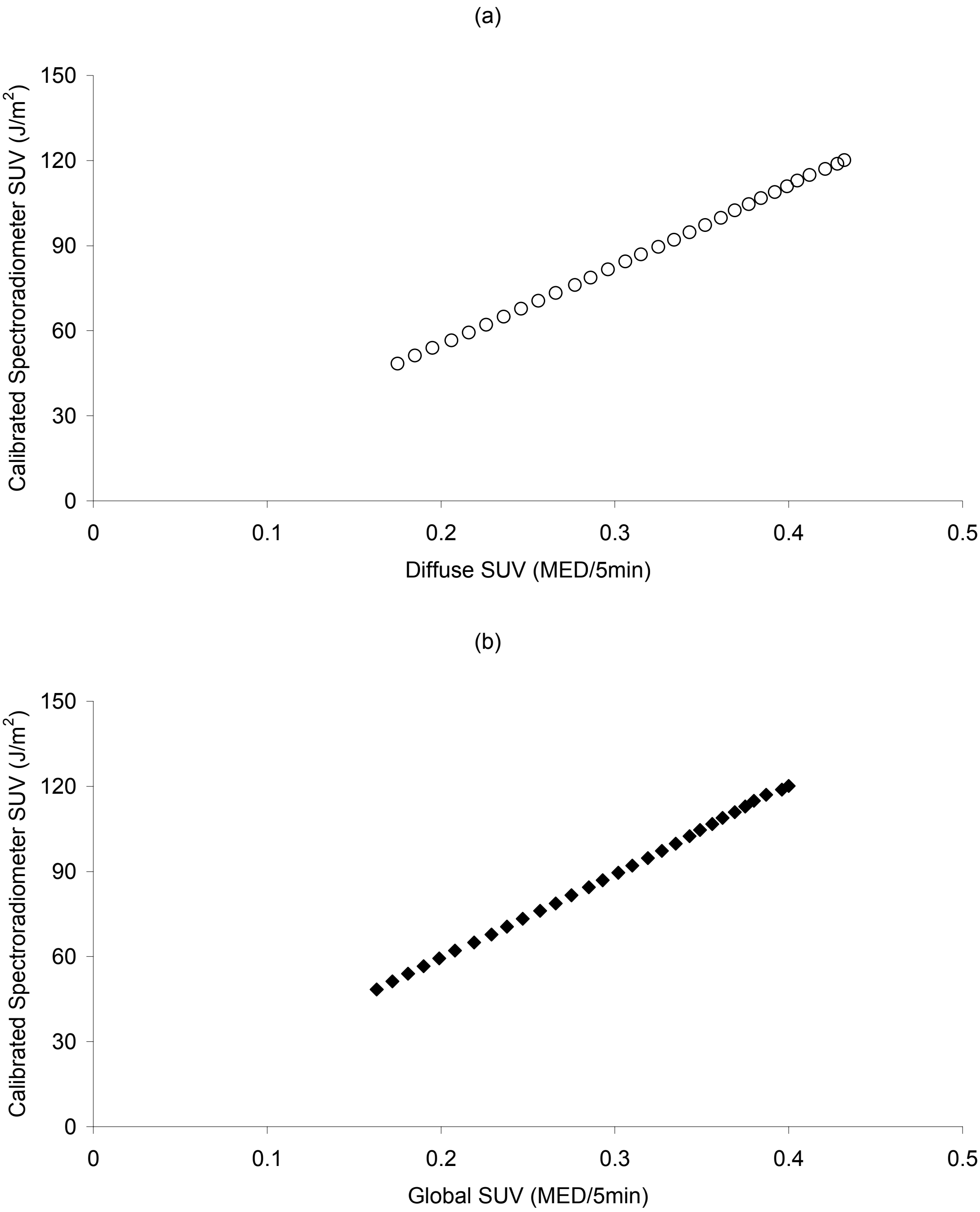
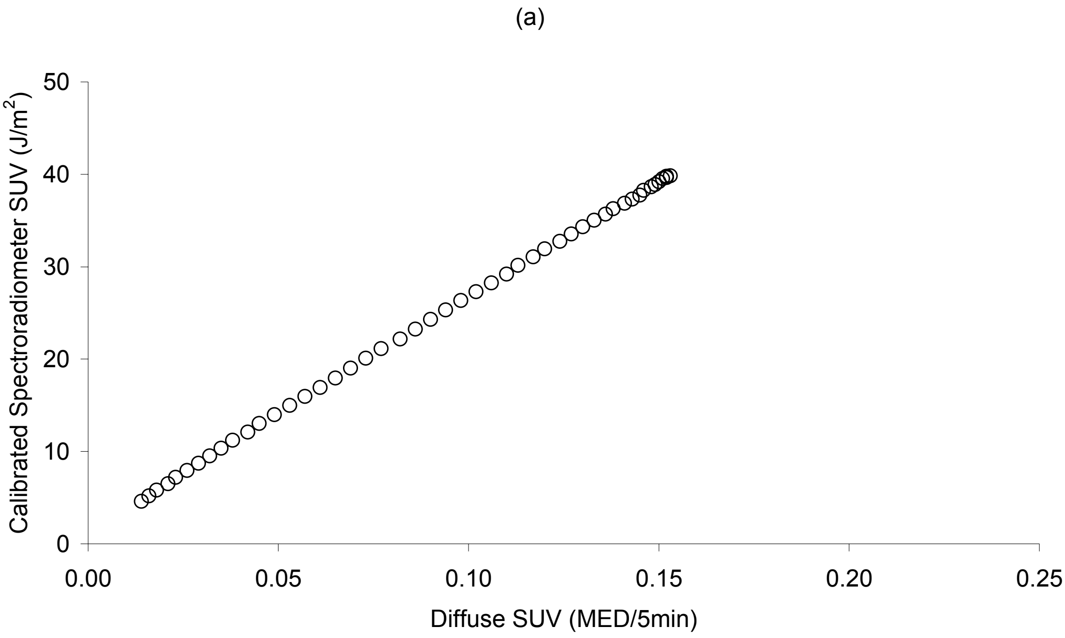


Figure A.4. Calibration of diffuse (a) and global (b) SUV meters for summer 2003/2004.



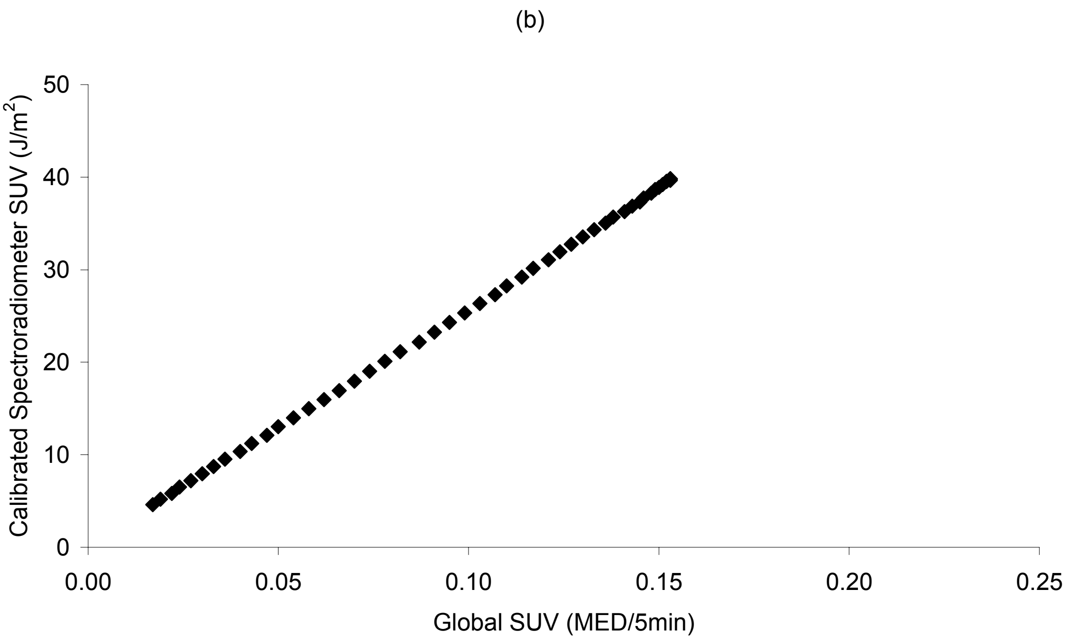
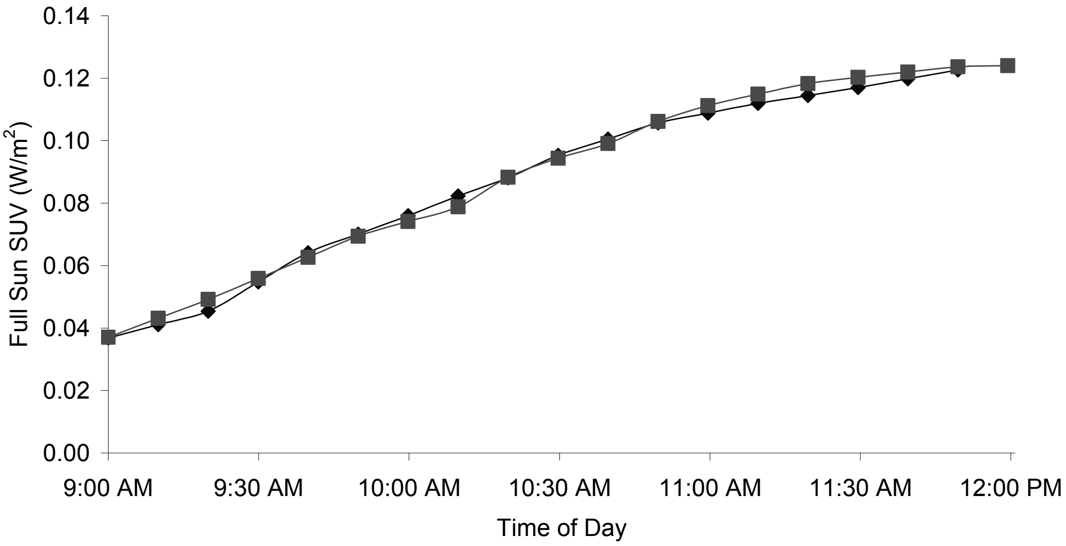


Figure A.5. Calibration of diffuse (a) and global (b) SUV meters for winter 2004.

Appendix B

Site Comparisons for Global UV

(a)



(b)

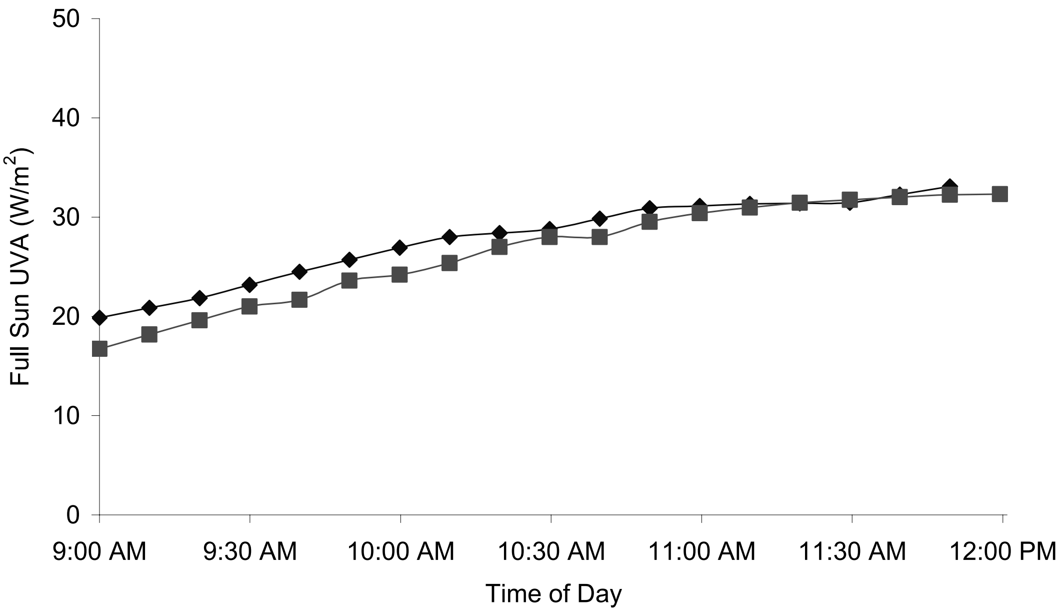
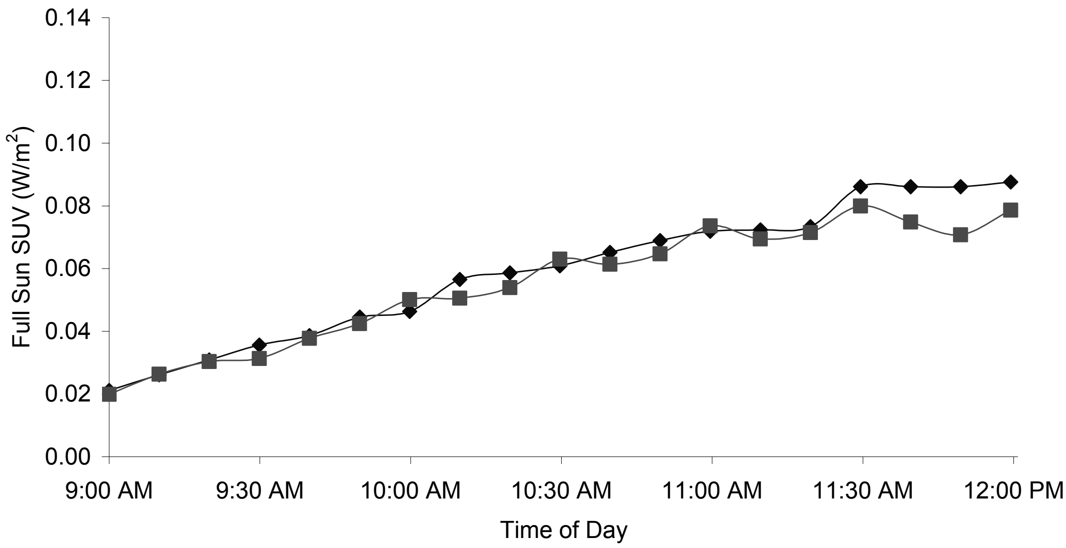


Figure B.1. Comparison of the global SUV (a) and UVA (b) near the small shade structure (♦) and from the global UV meters (■) at USQ.

(a)



(b)

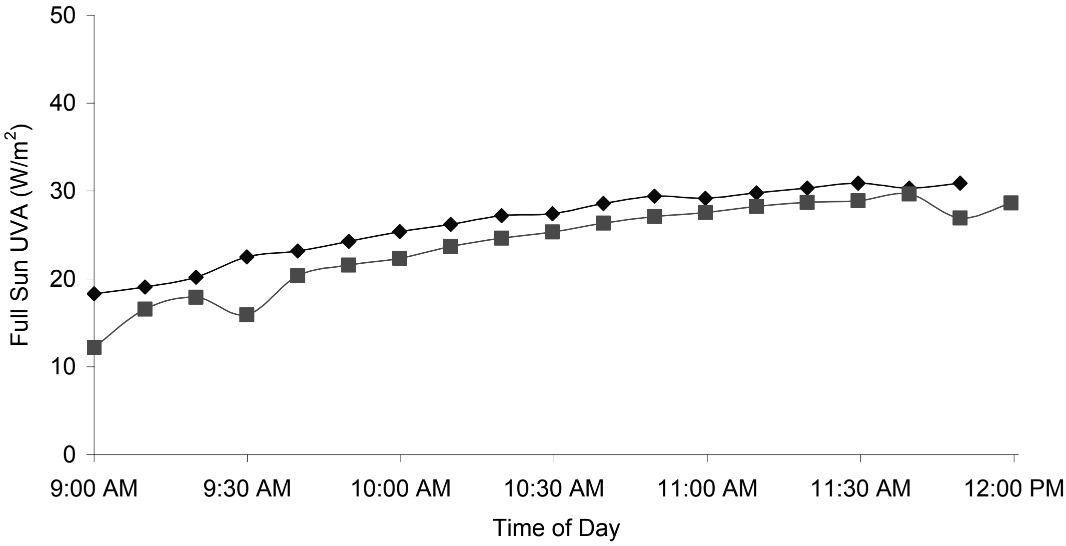
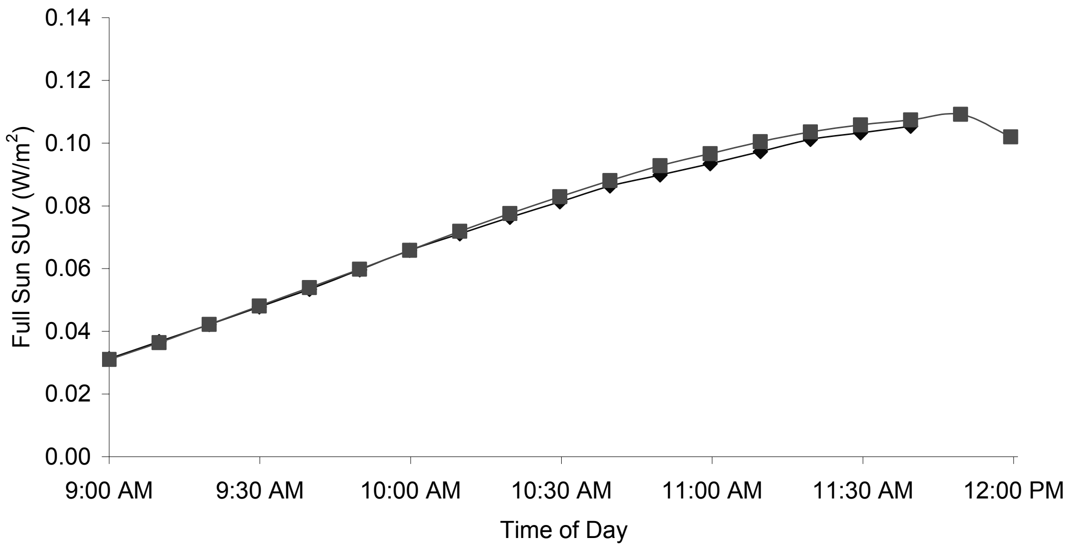


Figure B.2. Comparison of the global SUV (a) and UVA (b) near the medium shade structure (♦) and from the global UV meters (■) at USQ.

(a)



(b)

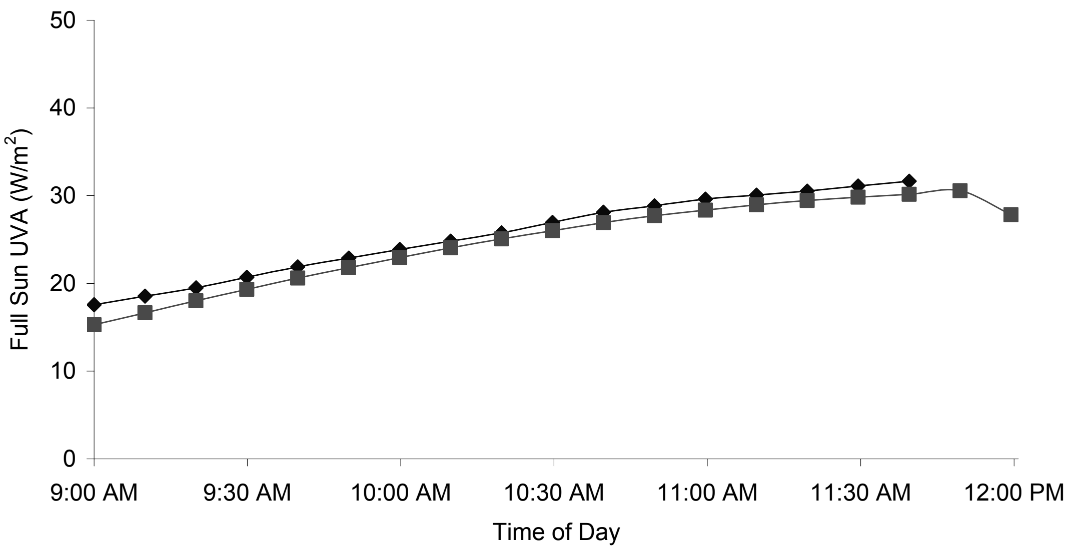


Figure B.3. Comparison of the global SUV (a) and UVA (b) near the large shade structure (♦) and from the global UV meters (■) at USQ.

Appendix C

Funding Opportunities

Funding Opportunities

There are a number opportunities available to community organisations for funding shade creation. Some of these are listed below. The list provided has been sourced from the following websites:

http://webtest.ipswich.qld.gov.au/,

http://www.qldcancer.com.au/

http://www.vichealth.vic.gov.au/

1. Gaming Machine Community Benefit Fund

This program provides one-off grants to eligible organisations up to $30,000. Eligible projects are:

- For the purchase of equipment associated with activities of the organisation,
- Special one-off events and activities,
- Community development and organisation development
- Minor Capital works
- Motor vehicle purchase costs

The grant allocation occurs on a quarterly basis.

Contact the Gaming Machine Community Benefit Fund for further information on 1800 633 619 or apply online at www.gcbf.qld.gov.au

2. Jupiter's Casino Community Benefit Fund

This program provides one-off grants to eligible organisations up to $150,000 are available. Eligible projects are:

- Capital Works
- Community education programs

- Workshops,

- Pilot programs for new or additional services

Preference is given to applications which indicate a high community involvement and where funds will benefit the community at large.

3. Queensland Events Regional Development Program

This program provides support towards regional events and is an initiative of the State Government and will focus on supporting events that:

- increase local economic activity and development
- enhance the appeal of the destination in which they are held
- enhance the visitor experience.

This program is open twice a year. For further information please contact QLD Events on (07) 4799 7301 or www.qldevents.com.au.

4. Minor Facilities Program – Sport and Recreation QLD

This program provides financial assistance to eligible organisations to undertake minor works to sport and recreation facilities to increase participation in sport and active recreation. This program focuses on small-scale building works.

5. Major Sport and Recreation Facilities program – Sport and Recreation QLD

This program provides financial assistance to eligible organisations to build, extend, upgrade or develop venues for regional sporting competition and for the community to participate in sport and active recreation. This program focuses on medium-scale building works.

6. National Standard Facilities Program – Sport and Recreation QLD

This program provides financial assistance to eligible organisations to build, extend, upgrade or develop venues to conduct state and national standard sporting competitions and international levels of training. This program focuses on large-scale venue building works.

These three programs are open once a year and for further information, please contact Sport and Recreation QLD on www.sportrec.qld.gov.au or phone (07) 3280 1875.

7. Club Development Program & Indigenous Community Development Program– Sport and Recreation QLD

This program aims to provide assistance towards sport and recreational organisations and indigenous community organisations to enhance their operations and will provide funding opportunities for planning, education, and training and participation initiatives.

This program is open once a year and for further information, please contact Sport and Recreation QLD on www.sportrec.qld.gov.au or phone (07) 3280 1875.

8. State Development Program – Sport and Recreation QLD

This program provides funding to state sporting organisations, state recreation organisations, industry service organisations, and industry peak bodies to assist the development and delivery of sport and physically active recreation in Queensland.

This program is open once a year and for further information, please contact Sport and Recreation QLD on www.sportrec.qld.gov.au or 3280 1875.

9. Australian Sports Foundation

The Australian Sports Foundation assists non-profit sporting organisations, schools, local councils and community organisations to raise money for valid sport related projects.

For further information please contact (02) 9256 0992

10. Australia Cricket Board – Cricket Club Facilities Program

For further information contact Queensland Cricket Association on (07) 3292 3100

11. Sunbusters

This program provides small grants to community organisations to assist them in developing or building shade structures. The program aims to support skin cancer prevention and encourages all organisations to adopt a SunSmart policy. Funding of up to $600 per organisation is available.

For further information please contact Queensland Health on 07 3818 5000.

12. Indigenous Sport Program

This program provided funding support to assist Indigenous communities/organisations in improving access to and the active participation of Aboriginal and Torres Strait Islander people in sport and recreation.

For further information please contact the Aboriginal and Torres Strait Islander Commission 07 3006 4822 or www.atsic.gov.au

13. School Improvement Assistance Scheme

The School Improvement Assistance Scheme (SIAS) assists Parents and Citizens' Associations to provide enhancements to school grounds and facilities. Assistance is provided in two forms: an annual Direct Grant to all eligible schools; and a dollar-for-dollar subsidy through the Major Works Improvement Program to Parents and Citizens' Associations for agreed projects, such as assembly halls and swimming pools.

For further information please contact Education Queensland on 07 3235 4005 or www.education.qld.gov.au

14. Philanthropy Australia Inc

This organisation has various resources available for purchase that list the numerous funding programs available.

For further information please contact Philanthropy Australia Inc on (03) 9650 9255.

15. SunSmart Newsletter

The SunSmart newsletter is sent quarterly all over Queensland and has information on shading grants – where organisations can apply for funding for shade structures.

16. Outdoor Sports Shade Grants

VicHealth has a scheme designed to assist local sporting clubs to provide shade structures for participants. Grants up to $2500 are available.

Appendix D

Publications from this Research

Photochemistry and Photobiology, 2003, 78(2): 180–183

Scattered UV Beneath Public Shade Structures During Winter¶

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ABSTRACT

Broadband field measurements were conducted beneath three different-sized public shade structures, small, medium and large, during winter in the Southern Hemisphere. These measurements were compared with the diffuse UV to quantify the relationship of the UV under and around the shade structures to the diffuse UV. For the shade structures, a relationship between the diffuse UV and the UV in the shade has been provided for clear skies and solar zenith angles (SZA) of 49–76°. This allows the prediction of the UV in the shade of these structures if the diffuse UV is known. The ultraviolet protection factors for the three shade structures ranged from 1.5 to 5.4 for decreasing SZA. For the greater SZA of 70–76°, the erythemal UV in the shade was 65%, 59% and 51% of that in full sun for the small, medium and large structures, respectively. For the smaller SZA of 50–53° the erythemal UV in the shade was 35%, 41% and 18% for the small, medium and large shade structures, respectively. From this research it can be concluded that the UV radiation levels in the shade in winter could cause erythema and other sun-related disorders.

INTRODUCTION

Solar UV radiation plays a considerable role in the health and development of human beings, from initiating the formation of vitamin D to increasing the risk of skin cancer and sun-related eye disorders. Because of the phenomena of Rayleigh and Mie scattering in the atmosphere, UV radiation is incident on a horizontal surface in two components, namely direct and diffuse. The direct component is incident in a direct path from the sun, whereas the diffuse component is scattered and incident from all directions. This diffuse UV may also constitute a significant contribution of the UV exposure to a nonhorizontal surface, *e.g.* to human eyes and skin, because it is incident from all directions and difficult to minimize with the use of hats and shade environments. As people become more aware about the damaging effects of UV radiation, they will seek shaded environments to reduce their personal UV exposure (1). Although shade does decrease direct UV levels, it is the diffuse UV that can still have high levels. Many people associate the degree of shading with the very welcome perception of a decrease in temperature; meanwhile, scattered UV can still reach the shaded skin, which is often unprotected (1).

Local governments provide many and various shaded environments for public use. These structures include gazebos, vegetation, shade cloth, polycarbonate sheeting and various opaque building materials (2). Various studies have been conducted to determine the levels of scattered radiation in different shade environments (1,3–6). Numerous guidelines on the construction of shade environments have also been developed (7–11). These studies have found that during summer approximately 60% of the UV that causes erythema was due to the diffuse component and that different shade environments provide different amounts of protection. Also, at times, the shade may not necessarily always be beneath the structure. At high solar zenith angles (SZA), it may be outside the structure as shown in Fig. 1. Although summer does have the highest levels of direct UV, it is not well documented how the levels of ambient diffuse UV influence the scattered UV beneath and around shaded environments. To the authors' knowledge, no previous research has concurrently measured the diffuse UV on a horizontal plane in full sun and the UV in the shade. This research compares the scattered UV levels beneath three specific shade structures, built by the local council, with that of the diffuse UV on an unshaded horizontal plane for clear skies at a Southern Hemisphere site during winter. The data gathered are significant because the relative proportion of scattered UV in shade is at its greatest for the higher SZA observed during winter.

MATERIALS AND METHODS

Shade structures. Three different public shade structures were used in this research and were located at varying public locations around Toowoomba (lat 27.5°S, long 151.9°E; 692 m above sea level), Australia. The three structures were chosen so that a range of differently sized public shade structures could be investigated. To a first order, the results are applicable to other shade structures of the same approximate dimensions that reduce the amount of sky view by the same approximate amount. None of the shade structures had any surrounding vegetation or other structures. The structures were three different gazebos of varying sizes and will be referred to as small, medium and large shade structures. Details of the shade structures are as follows:

- Small shade structure: The small shade structure is 2.55 m wide at the sides, 2.28 m high at the eaves and approximately 3.10 m high at the apex. The overhang of the roof is approximately 0.69 m, making the roof area of the small shade structure 15.5 m^2 (Fig. 1). This structure was chosen because it is situated between sporting ovals, where spectators seek to shade themselves.
- Medium shade structure: The medium shade structure is of hexagonal shape with sides measuring 2.16 m wide, 2.11 m high at the eaves, and approximately 3.31 m high at the apex. The overhang of the roof

¶Posted on the website on 20 June 2003

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Abbreviations: MED, minimal erythemal dose; RB, Robertson–Berger; SUV, erythemally active UV; SZA, solar zenith angle; UPF, ultraviolet protection factor; UVA, ultraviolet waveband 320–400 nm.

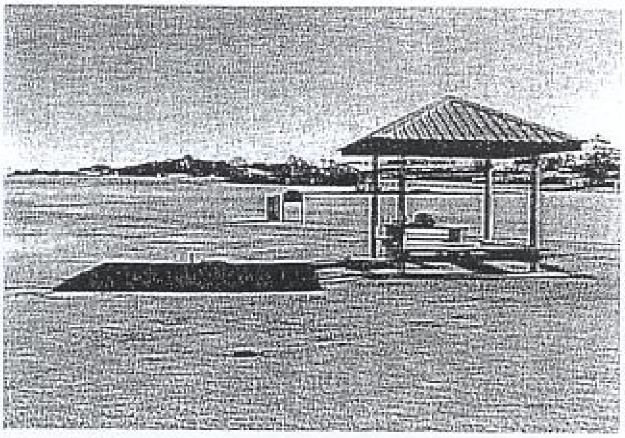

Figure 1. The small shade structure showing the resulting shade area at a high SZA.

is approximately 0.55 m, making the roof area 19.1 m^2. This structure was chosen because of its location in a park with no other forms of shade available.

- Large shade structure: The large shade structure is of an elongated octagonal shape with the longest sides of 2.30 m and the shortest sides measuring 2.10 m. The structure was 2.10 m high at the eaves and 2.85 m high at the apex and had an approximate overhang of 0.69 m. The roof area of the large shade structure was approximately 32.1 m^2. This was chosen because it is located at the corner of a sports field, where people will seek shade during sporting events.

The albedo of the grass surrounding the shade structures ranged from 4% in the shade to 6% in full sun, whereas the albedo of the concrete beneath the shade structure remained at approximately 10% for shade and full sun. The albedo of the grass was higher than usual; this was caused by dew on the grass.

The tables, seats and underside of the roofs also contributed varying amounts to the UV levels beneath the structure. For the small shade structure, the albedo of the table and seats was approximately 11% in full sun and up to 7% in the shade, with the albedo of the underside of the roof being approximately 2%. The albedo of the tables and seats in the medium and large shade structures was approximately 6% in full sun and 4% in the shade, with the underside of the roofs being approximately 2%.

When positioned in the center of the shade structures, the amount of sky view obstructed by the shade structures was calculated as 30%, 36% and 42% for the small, medium and large shade structures, respectively. This percentage was calculated as the area of the roof divided by the area of the roof and the sides.

Shade structure radiometry. Several broadband meters were used in this research to measure the solar irradiance and also the illumination. Three broadband sensors were used to measure scattered radiation beneath each of the shade structures; the erythemally active UV (SUV) (12), UV waveband 320–400 nm (UVA) and illuminance (lx) were measured. For this research, all measurements were taken in the center of the shade created by the shade structure and at a height of approximately 0.41 m from ground level on the horizontal plane. The height of the measurements roughly approximates that of young primary school children sitting on the ground. The UV irradiances and illuminance were measured in full sun and then in the shade of the shade structure every 10 min from 9:00 A.M. to 12:00 noon. The time between each shade and full sun measurement was less than 1 min. Two or three clear sky days were used to gather data for each shade structure during winter. For the winter measurements, the outside temperature ranged between 9 and 17°C, relative humidity ranged between 26% and 78% and ozone levels varied between 259 and 340 DU.

The UV irradiances were measured with a hand-held Robertson–Berger (RB) meter (model 3D V2.0, Solar Light Co., Philadelphia, PA) (13) fitted with a UVA detector and an erythemal weighted UV detector. The RB meter was intercompared with a scanning spectroradiometer for UV exposures and temperature variations on a clear day with an SZA between 50 and 66°,

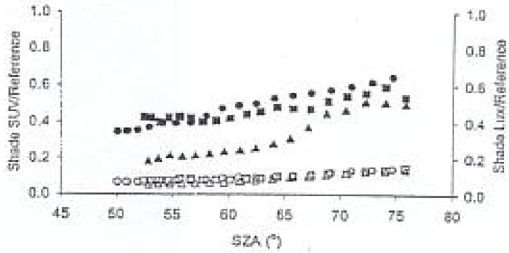

Figure 2. Shade ratios for the three shade structures, small (●), medium (■) and large (▲), for the SUV (●, ■, ▲) (left axis) and illuminance (○, □, △) (right axis). The reference is the corresponding irradiance in full sun.

the spectroradiometer was fitted with a 15 cm diameter integrating sphere (model OL IS-640, Optronics Laboratories, Orlando, FL). The uncertainty in the measured UV irradiance is estimated to be of the order of 10% for the RB meter. The spectroradiometer has a double holographic grating (1200 lines/mm) monochromator (model DH10, Jobin-Yvon, Longjumeau, France) connected to an R212 photomultiplier tube (Hamamatsu Co., Hamamatsu City, Japan) temperature stabilized by a Peltier cell temperature controller to 15.0 ± 0.5°C. Before each series of scans, the spectroradiometer was wavelength calibrated against UV mercury spectral lines, and absolute irradiance was calibrated against a quartz tungsten halogen lamp (250 W), operated at a constant direct current of 9.500 ± 0.005 A, from a current-regulated power supply (model PD36 20AD, Kenwood, Hazlet, N.J.). This secondary standard lamp calibration is traceable to the National Standards Laboratory at the CSIRO, Lindfield, Australia. Relative measurements of visible illuminance were measured with a light meter (model EMTEK LX-102, Walsh's Co., Brisbane, QLD, Australia).

Global and ambient broadband radiometry. Several global and ambient radiometers were used for this research: UVA, SUV and diffuse SUV (UV-Biometer Model 501 Version 3, Solar Light Co.) (14). The UVA and SUV radiometers measure the total global solar irradiance away from any shade. They are mounted on an unobstructed roof of the University of Southern Queensland, Toowoomba. The albedo of the environment surrounding the radiometers is approximately 7%. The differences in the UVA and SUV in full sun between this site and the shade structure sites were less than 10%. The shade structures were located within 7 km of the roof-mounted radiometers. The diffuse SUV radiometer was specifically set up to measure the diffuse erythemal radiation by way of using a shadow band to block the sun as it traverses across the sky. The error associated with the shadow-band of the diffuse SUV radiometer has been measured at approximately 10%, with the appropriate correction applied to all the necessary data. All three radiometers are temperature stabilized to 25°C and were intercompared with the scanning spectroradiometer described in the previous section, with an estimated uncertainty of the order of 10% for each of the radiometers.

RESULTS AND DISCUSSION

UV in the shade of the different structures

The results from the three shade structures used in this research can be generalized to other shade structures with similar sky view fractions, the same SZA range and no surrounding vegetation. The ratios of the SUV, UVA and illuminance in the shade and those in the corresponding full sun are shown in Figs. 2 and 3 as a function of SZA for clear skies. SUV and illuminance were plotted together to show the independence of the two measurements. There is negligible relationship between visible light intensity (illuminance) and UV levels in the shade. The three shade structures were plotted against each other to show how the UV and illuminance levels compare beneath each shade structure. For the higher SZA (greater than 65°), the erythemal UV ratio beneath the shade structures was 65%, 59% and 51% for the small, medium and large shade structures, respectively. UVA in the shade was not as high for the

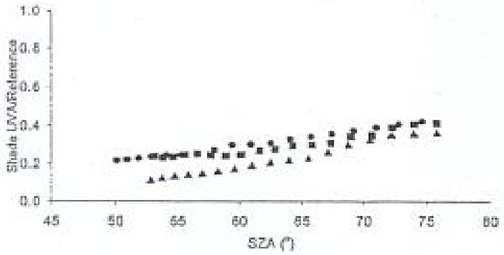

Figure 3. UVA shade ratios for the shade structures, small (●), medium (■) and large (▲), plotted against SZA.

higher SZA, which was expected because of the decreased scattering at the longer wavelengths; the percentages in the shade were 42%, 41% and 36%, respectively. UV levels beneath the large shade structures dropped significantly for the smaller SZA, with approximately 18% for SUV and 11% for UVA. The small and medium shade structures did not show as large a change at the smaller SZA, with SUV ratios of 35% and 43% and UVA ratios at 22% and 24%, respectively.

The relative proportion of SUV in the shade of the large shade structure decreases more rapidly than that for the other shade structures as the SZA decreases; this reduction can be attributed to the larger roof area obscuring more of the sky at the smaller SZA. When comparing SUV with UVA, the shade ratios for SUV are much higher than for UVA. This is due to Rayleigh scattering, resulting in increased scattering at the shorter wavelengths. There is also less difference between shade structures for the UVA shade ratios, which shows that roof area has a more important role in decreasing the scattered SUV than the UVA.

Figure 4a shows the levels of erythemal UV that people situated in the center of the shade may be exposed to, for a changing SZA. Figure 4b shows the UVA irradiances encountered beneath each shade structure and how these levels change as the SZA changes. For UVA, an apparent increase was observed for the large shade structure from 4.3 to 7.7 W/m^2 as the SZA increased, whereas the small and medium shade structures showed little change, 8.6–10.0 and 8.8–9.0 W/m^2, respectively, as the SZA increased. The levels of SUV beneath the small and medium shade structures showed a general decrease as SZA increased, 0.14–0.08 minimal erythemal doses (MED)/10 min and 0.13–0.04 (MED)/10 min, respectively, whereas the levels beneath the large shade structure increased from 0.06 to 0.08 MED/10 min, before eventually decreasing to 0.04 MED/10 min at the larger SZA. The increase in UVA for the large shade structure could be attributed to Mie scattering at the time of the measurements. Small amounts of cloud were observed, but none covered the solar disk. The reduction in SUV for the shade structures was due to the decrease in sky view as the SZA decreased, resulting in diminishing the distance from the center of the shade to the center of the shade structure. Specifically, as the shaded area shifted to be under the structure with decreasing SZA, there was less sky view.

UV protection factor

The shade ratios were used to obtain the UV protection factors (UPF) for each shade structure. These are plotted as a function of SZA in Fig. 5. A definite decrease in UPF occurred as the SZA increased for each of the shade structures; this decrease was due to the increase in the relative proportion of the scattered UV as a result of the larger SZA. The increase in UPF for the large shade structure, at the smaller SZA, can be attributed to the fact that the center of the shade received more protection from the roof (decreased amount of sky view) when compared with the other shade structures.

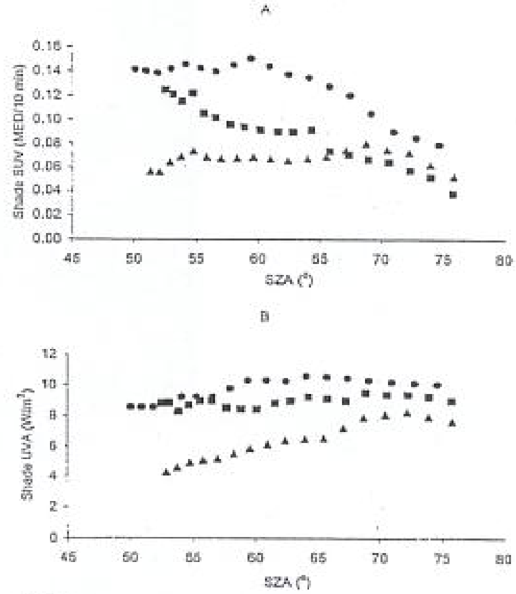

Figure 4. UV levels encountered beneath the shade structures, small (●), medium (■) and large (▲), as a function of SZA for the erythemal UV (A) and UVA (B) wavebands.

UV in shade and diffuse UV

Figure 6 shows the relationship between the diffuse UV in the sun as measured by the roof-mounted radiometers and the scattered UV in the shade measured for each of the shade structures. From this plot the relationships between the diffuse UV and the scattered UV beneath these three shade structures can be obtained for the range of SZA of 49–76°.

For clear sky days and SZA of 49–76°, the relationships are Small shade structure

$$y = -20.0x^2 + 2.5x - 0.03 \quad (1)$$

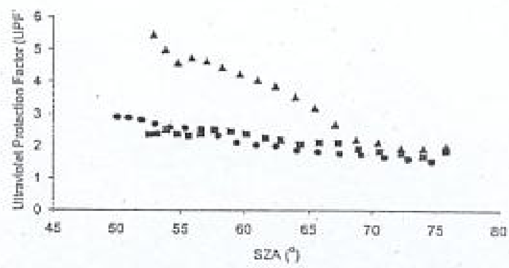

Figure 5. UPF for each shade structure, small (●), medium (■) and large (▲), as against SZA.

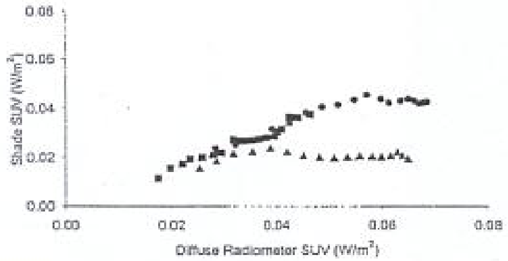

Figure 6. Scattered UV in the shade of the structures compared with diffuse UV measurements. The measurements are for the small (●), medium (■) and large (▲) shade structures.

Medium shade structure

$$y = 2.6x^2 + 0.7x + 0.001 \quad (2)$$

Large shade structure

$$y = -7.2x^2 + 0.7x + 0.01 \quad (3)$$

where x is the diffuse UV.

From the relationships obtained for each shade structure, field measurements were conducted and compared against the models for a range of SZA from 56 to 62°. For the small, medium and large shade structures, variation between the field measurements and those of the models was approximately 6%, 6% and 9%, respectively. The error due to albedo from the various parts of the shade structure has been factored into the models.

CONCLUSIONS

Even in winter the erythemal UV in full sun can be more than adequate to induce erythema, with levels reaching approximately 2.5 MED/h during the middle of the day. From this research it can be concluded that these specific shade structures are inadequate for providing the public enough protection against damaging UV radiation for changing SZA. Figure 1 shows the small shade structure used for this research and how ineffective it is for shading the seats and benches for large SZA. UPF are analogous to *x* sun protection factor, the larger the better. With a maximum UPF of 5.4 for the large shade structure, more research is needed to show what effect side-on protection (*i.e.* trees and shrubs) would have in increasing the UPF. Although the UPF for the three shade structures are insufficient, it is still recommended to use shade as a UV minimization strategy when outdoors. However, additional sun protection strategies such as hats, appropriate glasses and sunscreen should still be used, even if seeking shade, for an extended period of time during the winter months. For the shade structures used in this research, a relationship between the diffuse UV and the UV in the shade has been provided for clear skies and SZA of 49–76°. This allows the evaluation of the UV in the shade of these shade structures if the diffuse UV can be measured or modeled.

Acknowledgements—The authors wish to acknowledge Graham Holmes and Oliver Kinder of the Faculty of Sciences, University of Southern Queensland, for their assistance.

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Annual variation of the angular distribution of the UV beneath public shade structures

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Received 10 March 2004; received in revised form 19 July 2004; accepted 22 July 2004
Available online 27 August 2004

Abstract

Local governments provide many shade structures at parks and sporting ovals for public use. However, the question remains of how effective are public shade structures at reducing biologically effective UV radiation throughout the year? Broadband measurements of the angular distribution of scattered UV beneath three specific public shade structures was conducted for relatively clear skies and for a solar zenith angle (SZA) ranging from 13° to 76°. The ultraviolet protection factors (UPF) for the shade structures ranged from 18.3 to 1.5 for an increasing SZA. Measurements showed that the horizontal plane received the highest SUV levels from the SZA of 28° to 75°, 42° to 76°, and 50° to 76° for the small, medium and large structures, respectively. This was due to the angle of the sun causing the shade created by the shade structure to be outside the structure. For the small shade structure, the measurements directed to the west were the highest levels in the shade after approximately 28°. For the medium and large shade structures, the measurements directed to the west and south were the highest levels in the shade after roughly 42° and 50°, respectively.

Keywords: Diffuse; Angular; UV; Shade structures; Protection factor

1. Introduction

Australia has the unenviable reputation of having one of the highest rates of mortality for skin cancer in the world. Skin cancer has been linked to excessive and repeated exposures to solar UV radiation [1,2] and causes more than 1000 deaths in Australia each year, with the majority of these being preventable. The health effects of solar UV radiation vary significantly, from being a morale booster to the severe degradation of body tissue. Solar UV radiation at the Earth's surface is influenced by a number of factors, namely time of day, atmospheric ozone, aerosols, cloud cover, albedo, and seasonal and geographical variation [1,3]. While direct UV from the sun is generally reflected or absorbed by the shade environment, the diffuse component is still present in the shade and the lack of knowledge on diffuse UV leads to misconceptions regarding the amount that shade protects the human body against UV radiation [4].

Seasonal variation in temperature can play a significant role in determining a person's exposure to UV radiation. During summer, people may seek shade or utilise other UV minimisation strategies in the hottest part of the day for comfort [5] and also because they have been educated about the dangers of direct summertime UV. For the colder winter month's people may spend longer outside as they seek the warmth from the sun when outside and as they believe they are at a greatly decreased risk of exposure to harmful UV.

While past research has measured seasonal variation of UV in full sun (e.g. [6–10]), only a small amount of research has been conducted on seasonal variation of

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doi:10.1016/j.jphotobiol.2004.07.006

UV beneath different shade environments (e.g. [3,4,11–14]). This previous research has found that the percentage of erythemal UV in tree shade compared to that in full sun is higher in winter compared to summer [3]. However, the absolute erythemal UV irradiances in the tree shade were still higher in summer due to the higher irradiances in full sun. For public shade structures, the UV exposure under the structures is determined by the design and construction of the structure [4]. The ultraviolet protection factor (UPF) has been shown to decrease with solar zenith angle (SZA) between 33° and 76° [4,13]. Additionally, the solar UV exposures in shade have been shown to be dependent on the angle of the receiving surface [12].

Consequently, this paper extends this previous research and reports the findings of concurrent measurements of the diffuse UV on a horizontal plane in full sun and the angular distribution of UV in the shade of three public shade structures for the broad range of solar zenith angles seen throughout the year. This research compares the UV levels on horizontal and vertical planes directed to the north, south, east and west beneath and around three specific different sized public shade structures with that of the diffuse UV on an unshaded horizontal plane for clear skies at a Southern Hemisphere site.

2. Materials and methods

2.1. Shade structures

The three public shade structures employed in this research were located at varying public locations around the city of Toowoomba (27.5°S, 151.9°E, 692 m above sea level), Australia. The three structures were chosen because of their differences in size and shape. To a first order, the results are applicable to other shade structures of the same approximate dimensions that reduce the amount of sky view by the same approximate amount. None of the shade structures had any surrounding vegetation or other structures in close proximity. The structures will be referred to as the small, medium and large shade structures (refer to Fig. 1). Descriptions of the shade structures have been provided elsewhere [13]. Briefly, they are as follows:

- *Small shade structure*: The small shade structure is 2.55 m wide at the sides, 2.28 m high at the eaves and approximately 3.10 m high at the apex. The overhang of the roof is approximately 0.69 m.
- *Medium shade structure*: The medium shade structure is of hexagonal shape with sides measuring 2.16 m wide, 2.11 m high at the eaves, and approximate 3.31 m high at the apex. The overhang of the ro is approximately 0.55 m.

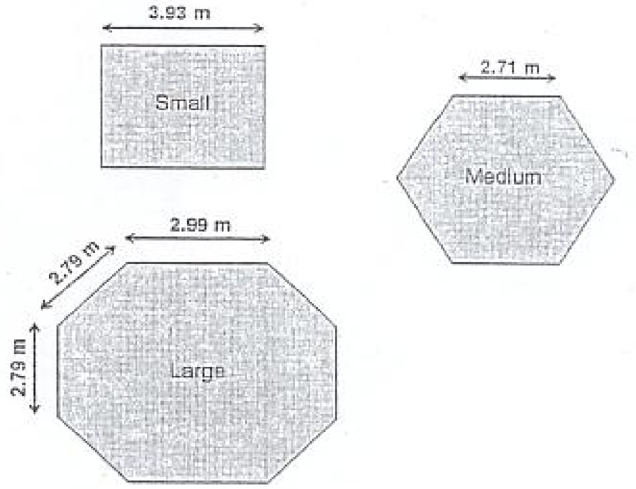

Fig. 1. A top-view schematic representation of the roofs of the three shade structures used for this research.

- *Large shade structure*: The large shade structure is of an elongated octagonal shape with the longest sides of 2.30 m and the shortest sides measuring 2.10 m. The structure was 2.10 m high at the eaves, 2.85 m high at the apex and had an approximate overhang of 0.69 m.

The albedo of the grass surrounding the shade structures ranged from 4% in the shade to 7% in full sun, while the albedo of the concrete beneath the shade structure stayed at approximately 10% for shade and full sun. Descriptions of sky view and albedo related to the tables, seats and underside of roofs have been provided elsewhere [13].

2.2. Shade structure radiometry

Two broadband sensors were used in this research to measure the solar UV irradiance beneath each of the shade structures; the erythemal UV (SUV) [15] and UVA (320–400 nm) were measured. For this research all measurements were taken in the centre of the shade created by the shade structure and at a height of approximately 0.41 m from ground level, which roughly approximates young primary school children sitting on the ground. For the lower SZAs seen during summer the measurements in the shade were conducted either on the seats or on the tables. The UV irradiances were measured on a horizontal plane in full sun and then on horizontal and vertical planes in the shade of the shade structure every 10 min from 9 am to 12 noon. The vertical plane measurements were directed north, south, east and west to account for the side-on scattered UV. The time between each shade and full sun measurement was less than 1 min. Two or three clear sky days were utilized to gather data for the range of SZAs.

For the measurements, the outside temperature ranged between 9 and 35 °C, relative humidity ranged between 26% and 92% and ozone levels varied between 248 and 347 DU.

A hand held Robertson-Berger (RB) meter (model 3D V2.0, Solar Light Co., Philadelphia, PA, USA) [16] fitted with a UVA detector and an erythemal weighted UV detector was used to measure the UV irradiances. The RB meter was calibrated against a scanning spectroradiometer for UV exposures and temperature variations on a clear day with an SZA between 16° and 66°. The scanning spectroradiometer based on a double grating monochromator, integrating sphere and photomultiplier tube [13] was employed to measure the UV spectrum in 1 nm increments in the sun (model OL IS-640, Optronics Laboratories, Orlando, FL, USA). The uncertainty in the measured UV irradiance is estimated to be of the order of 10% for the RB meter.

2.3. *Diffuse broadband radiometry*

A diffuse SUV broadband radiometer (UV-Biometer Model 501 Version 3, Solar Light Co.) [17] mounted on an unobstructed roof of the University of Southern Queensland, Toowoomba, was also employed in this research. The diffuse SUV radiometer was specifically designed to measure the diffuse erythemal radiation by making use of a shadow band to block the sun as it traversed the sky throughout the day and the year. The error associated with the shadow-band of the diffuse SUV radiometer has been measured at approximately 10% with the appropriate correction applied to all of the necessary data. The diffuse SUV radiometer is temperature stabilized to 25 °C and was calibrated against the scanning spectroradiometer described in the previous section, with an estimated uncertainty of the order of 10%.

3. Results and discussion

3.1. *Shade structures and scattered UV*

Figs. 2–4 are based on the maximum UV levels in the shade obtained from either the vertical or horizontal measurements. The horizontal plane received the highest SUV levels from the SZA of 28° to 75°, 42° to 76°, and 50° to 76° for the small, medium and large structures, respectively. This was due to the angle of the sun causing the shade created by the shade structure to be outside the structure. As the SZA decreased, the levels of UV in the shade decreased on the horizontal plane and increased for the vertical planes. For the small shade structure, the measurements directed to the west were the highest levels in the shade after approximately 28°. For the medium and large shade structures, the measurements directed to the west and south were the highest levels in the shade after roughly 42° and 50°, respectively. This apparent increase in vertical plane measurements was due to the decrease in sky view on the horizontal plane which in turn decreased the levels of UV on the horizontal plane.

Fig. 2 shows the comparison of the annual levels of SUV in the shade of the three shade structures as a function of SZA for clear skies. For the SZAs of 44° to 53°, the erythemal UV beneath the shade structures was at a maximum. The maximum values were 0.16, 0.12 and 0.09 MED/10 min for the small, medium and large shade structures, respectively. The lowest SUV levels in the shade for the small and medium shade structures were 0.07 and 0.03 MED/10 min, respectively, at a SZA of approximately 75°. However, the lowest levels for the large shade structure were observed at approximately 14° with 0.03 MED/10 min. SUV levels in the shade of the three structures increased as the SZA decreased from

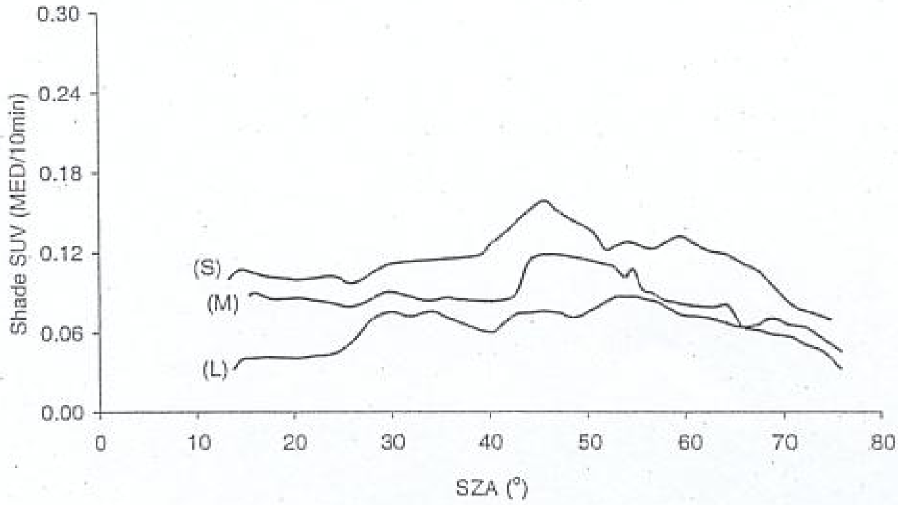

Fig. 2. Maximum SUV levels encountered beneath the shade structures, small (S), medium (M) and large (L), as a function of SZA.

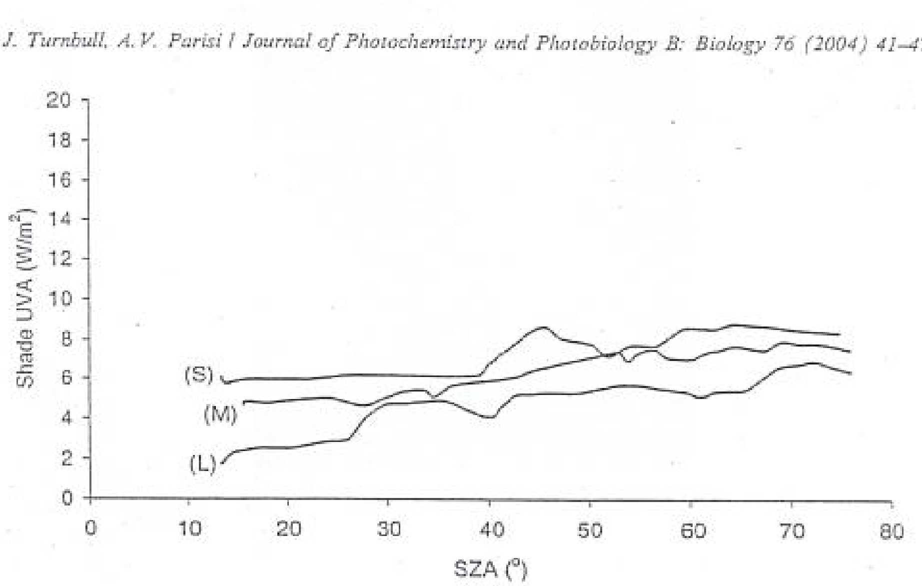

Fig. 3. Maximum UVA levels encountered beneath the shade structures, small (S), medium (M) and large (L), as a function of SZA.

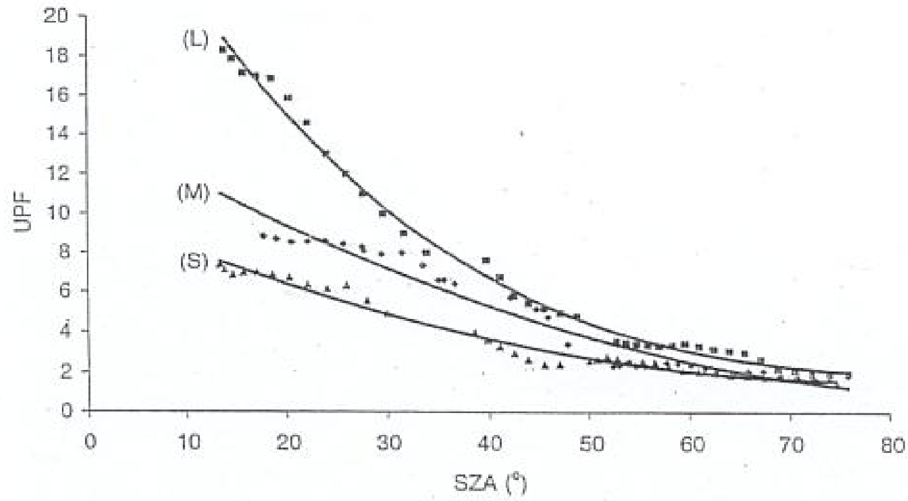

Fig. 4. Ultraviolet protection factors for each shade structure, small (S), medium (M) and large (L), as a function of SZA.

approximately 76° to 45° before decreasing as the SZA decreased.

Fig. 3 shows UVA levels in the shade for the three shade structures. UVA levels in the shade showed a general decreasing trend as the SZA decreased. Maximum UVA levels measured beneath the shade structures were 8.8, 7.9 and 6.9 W/m^2 for the small, medium and large shade structures, respectively. The lowest UVA levels measured beneath the shade structures were 5.1, 4.6 and 1.8 W/m^2 for the small, medium and large shade structures, respectively.

The relative proportion of SUV in the shade of the large shade structure decreases more rapidly than the other shade structures as the SZA decreases, this reduction can be attributed to the larger roof area obscuring more of the sky at the smaller SZAs. When comparing SUV to UVA shade ratios (refer to Table 1), the levels of SUV are much higher than for UVA because erythemal UV is more biologically effective in the UVB waveband than the UVA. Consequently, Rayleigh scattering results in increased scattering at the shorter wavelengths associated with the UVB waveband. There is also less difference between the shade structures for the UVA shade ratios; this shows that roof area has a more important role in decreasing the scattered SUV than the UVA.

The reduction in SUV for the shade structures is due to the decrease in sky view as the SZA decreased, resulting in diminishing the distance from the centre of the shade to the centre of the shade structure. Specifically, as the shaded area moved to be under the structure with decreasing SZA, there was less sky view.

Table 1
The maximum and minimum observed shade ratios for the three shade structures of small, medium and large

Shade ratios	SUV	UVA
Small		
Max	0.65	0.42
Min	0.14	0.12
Medium		
Max	0.59	0.41
Min	0.11	0.09
Large		
Max	0.51	0.36
Min	0.05	0.03

3.2. Annual variation in UV protection factors

The ultraviolet protection factors for each shade structure are plotted as a function of SZA in Fig. 4. An obvious decrease in UPF occurs as the SZA increases for each of the shade structures; this decrease takes place due to the increase in the relative proportion of the scattered UV as a result of the larger SZA. However, such a decrease does not necessarily mean an increase in UV levels beneath the shade structures. As Fig. 2 shows, the highest levels of UV measured in the shade were around a SZA of between 44° and 53°. The increase in UPF for the large shade structure, at the smaller SZAs, can be attributed to the fact that the centre of the shade received more protection from the roof (decreased amount of sky view) when compared to the other shade structures.

For clear sky days and SZAs of 13° to 76° the relationships are:

Small shade structure

$$y = 0.0014x^2 - 0.2x + 10.2. \quad (1)$$

Medium shade structure

$$y = 0.0016x^2 - 0.3x + 14.7. \quad (2)$$

Large shade structure

$$y = -4 \times 10^{-5}x^3 + 0.011x^2 - 0.95x + 30.1, \quad (3)$$

where x is the SZA and y is the UPF of the shade structures. The coefficient of determination for Eqs. (1)–(3) are 0.98, 0.95 and 0.99, respectively. A cubic polynomial is used for the large shade structure to give it a better fit for the large SZA. The fit for the large shade structure is better presented as a cubic polynomial.

3.3. Diffuse UV and UV in the shade

Fig. 5 shows the relationship between the diffuse UV in the sun as measured by the roof-mounted radiometer and the scattered UV in the shade measured for each of the shade structures. From this plot the relationships between the diffuse UV and the scattered UV beneath these three shade structures can be obtained for the range of SZAs of 13° to 76°.

For clear sky days and SZAs of 13° to 76° the relationships are:

Small shade structure

$$y = 17679x^4 + 512x^3 - 71.8x^2 + 3.8x - 0.0372. \quad (4)$$

Medium shade structure

$$y = -1180x^4 - 4083.3x^3 + 318.36x^2 - 9.422x + 0.123. \quad (5)$$

Large shade structure

$$y = -3591x^4 + 1038.2x^3 - 113.5x^2 + 5.223x - 0.058, \quad (6)$$

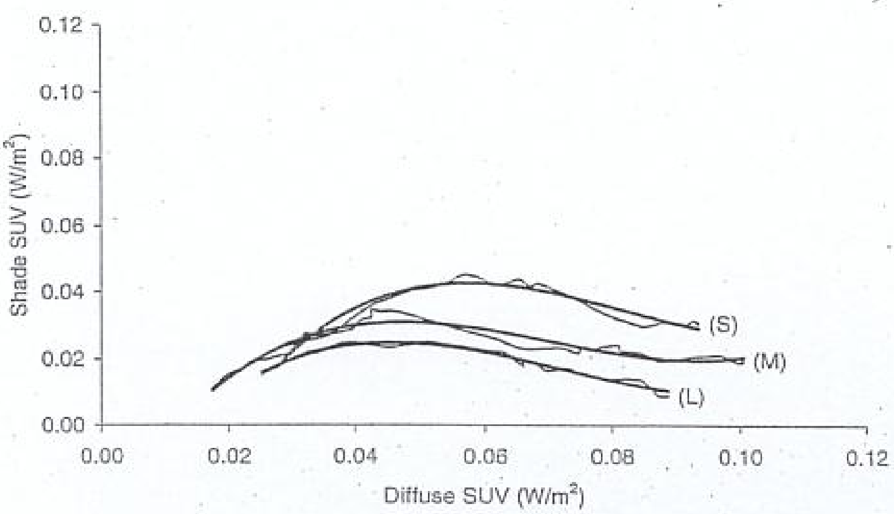

Fig. 5. Scattered SUV in the shade of the structures compared with diffuse SUV measurements.

where x is the diffuse UV and y is the scattered UV in the shade of the shade structures on a horizontal plane. The coefficient of determination for Eqs. (4)–(6) are 0.98, 0.89 and 0.96, respectively.

From the relationships obtained for each shade structure, field measurements were conducted and compared against the models for a range of SZA from 11° to 66°. For the small, medium and large shade structures variation between the field measurements and those of the models was up to approximately 11%, 5% and 11%, respectively.

4. Conclusions

The research presented above is significant because it extends previous work by Turnbull et al. [13] which looked at scattered UV levels in the shade on a horizontal plane during winter. Previous research has measured the variation that diffuse UV exhibits with a changing SZA. For example, Parisi et al. [18] measured the difference between the relative proportions of diffuse UVB and UVA where the percentage diffuse UVB ranged from 23% at noon to 59% at 3 pm and the percentage diffuse UVA ranged from 17% to 31% for the same times. Likewise, the diffuse UVB has been measured on clear days and has been shown to range from 48% to 70% for solar zenith angles of 15° and range to 100% for solar zenith angles of 75° [19].

This current study contains data on the scattered UV incident from the vertical to horizontal planes and for the SZA observed throughout an entire year. These angular measurements are crucial in showing that research into the effects of side-on protection is essential.

When constructing shade structures, careful consideration must be given to these findings because, even though summer has the highest UV levels in the full sun, winter has the highest relative proportion of scattered UV in the shade due to the increased scattering resulting from the longer path of the solar UV through the atmosphere. Shade is certainly important as a UV minimisation strategy. However, the message is that for long periods, shade alone does not provide enough protection from some biologically damaging UV. Even though the UV transmission through the materials employed on the roof of the structures may be very low, it is the construction of the entire shade setting that determines the exposure beneath that structure. Shade structures that have trees, shrubs or buildings in close proximity generally have lower levels of UV in the shade than those having no such surrounding objects.

During a winter in south east Queensland, full sun UV radiation can reach levels of approximately a third or more of that registered in the middle of the day during summer. Therefore, it is necessary for people who live in similar latitudes to minimise UV exposure under all climatic conditions, throughout the year.

From this research it can be concluded that these specific shade structures are inadequate for providing the public enough protection against damaging UV radiation for changing SZA. The shade structures used in this research had no side-on protection, therefore further research is needed to show how effective side-on protection would be at changing a shade structures UPF.

There are countless ways of preventing sunburn and other deleterious effects due to excess sun exposure. Prevention behaviours include simple things such as: wearing hats, appropriate clothing, sunglasses, sunscreens and seeking shade. These prevention behaviours need to be used in conjunction with one another; otherwise the full sun protective affect will not occur.

5. Abbreviations

UV	ultraviolet radiation
SZA	solar zenith angle
UPF	ultraviolet protection factor
SUV	erythemal ultraviolet
UVA	ultraviolet radiation (320–400 nm)
DU	Dobson units
RB	Robertson–Berger
MED	minimum erythemal dose

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Increasing the ultraviolet protection provided by shade structures

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Received 19 April 2004; received in revised form 26 July 2004; accepted 3 September 2004
Available online 23 November 2004

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° and up to 30% for the smaller SZA of approximately 11° 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 the 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

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doi:10.1016/j.jphotobiol.2004.09.002

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 Fig. 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 (Fig. 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 Fig. 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

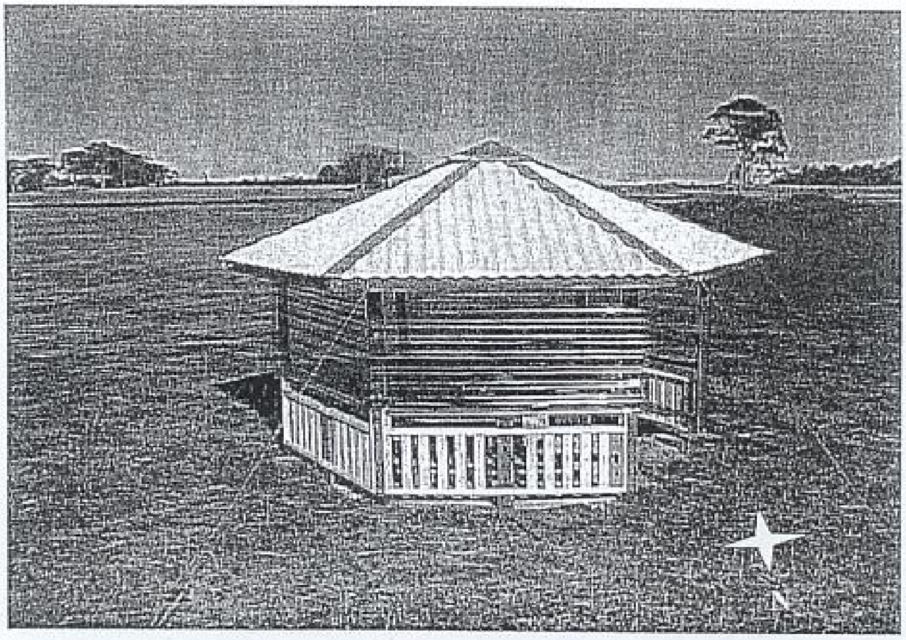

Fig. 1. The half-size scale model and the clear tint polycarbonate sheeting attached to two sides.

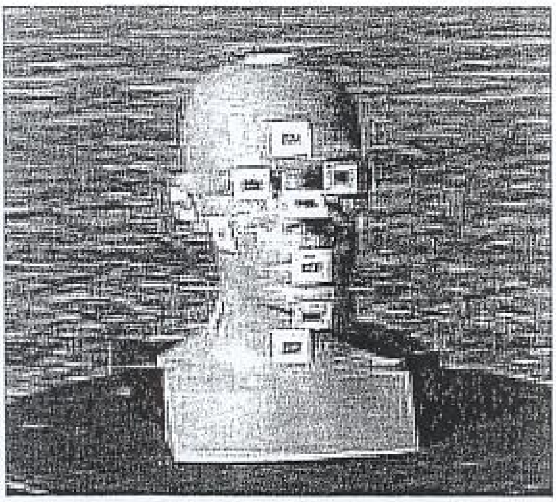

Fig. 2. The manikin head forms used and some of the anatomical facial dosimeter sites.

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 min 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 Eq. (1) for each 5 min 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 $S(\lambda)$ is the spectral irradiance measured with the spectroradiometer, $A(\lambda)$ is the erythemal action spectrum [14] and $\Delta\lambda$ 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 295–400 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 Fig. 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.

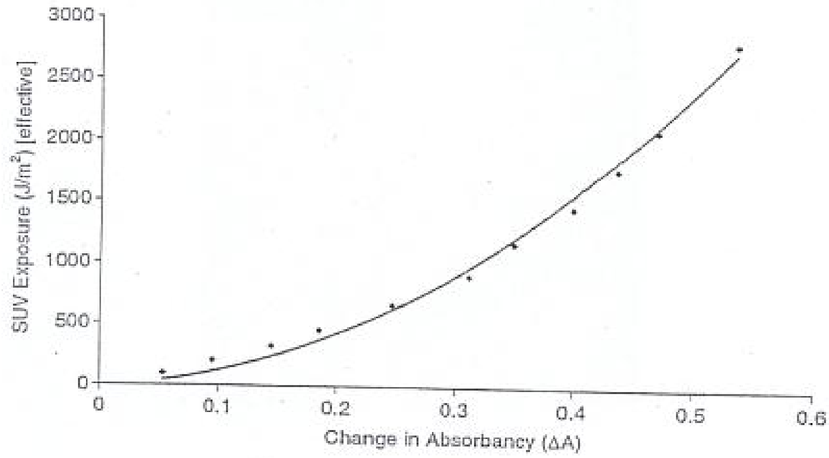

Fig. 3. Dosimeter calibration curve.

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

Facial site	Summer (exposure shade ratios)				Winter (exposure shade ratios)			
	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

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 Fig. 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

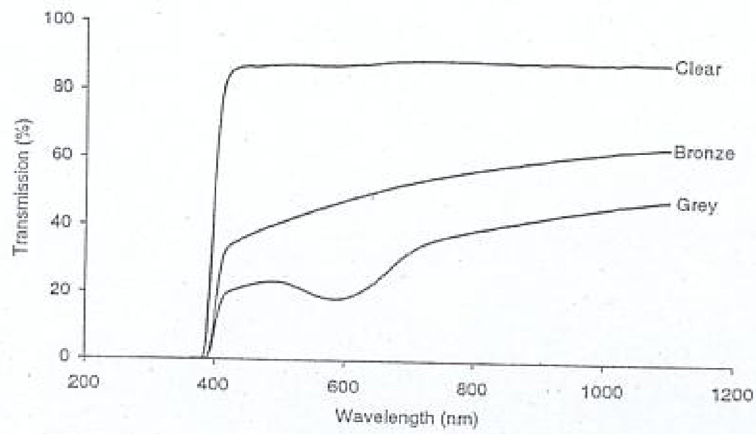

Fig. 4. The spectral transmission properties of the three types of polycarbonate sheeting used in the research.

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 (△) had varying amounts of vegetation on the north-western, western and south-western sides. Shade structure (○) 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° to 60°.

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 Fig. 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 (△) 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 (○) 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

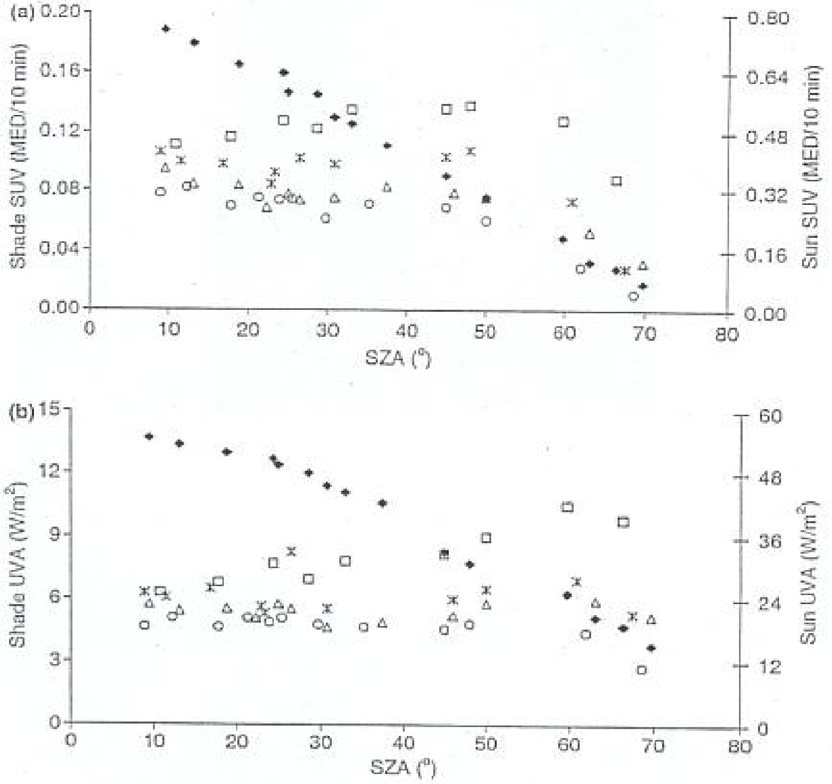

Fig. 5. Maximum UV exposures observed from the horizontal and vertical planes beneath the four shade structures, (a) □, (b) △, (c) ○, (d) ✻, compared to full sun (◆) (right axis).

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
a □	0.14	0.09
b △	0.10	0.03
c ○	0.08	0.01
d ✻	0.11	0.03

erythemal UV levels of 0.11 MED/10 min and 0.03 MED/10 min, respectively.

As can be seen in Fig. 5 a and b, 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° to 70°. At the low SZA of approximately 10° to 20° 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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10TH CONGRESS OF THE EUROPEAN SOCIETY FOR PHOTOBIOLOGY

The European Society for Photobiology (ESP) recently held its 10th Congress in Vienna, Austria, from the 6-11 September, 2003. As with previous meetings, the programme of the 10th Congress covered all major fields of photobiology. There was a mixture of photobiology update special lectures, 37 different symposia, workshops and 2 poster sessions. Over 250 oral presentations and 180 posters where presented during the weeklong congress. The congress addressed a wide range of topics, from DNA damage and repair to the protective ability of different shade structures, which indicates the very diverse research that is being carried out all over the world. Unlike previous congresses, this year's programme included for the first time a joint symposium co-organised by the European Photochemistry Association (EPA) and the ESP. This reflected the close association between the research being conducted by the members of both societies. Attendees of the conference came from all over the world to listen and to discuss the diverse area that photobiology entails.

The Queensland branch of the AIP recently awarded me a $500 grant to attend the congress, where I was able to present my research entitled "UV Protection and Shade Structures". Part of a research focus in the Centre for Astronomy, Solar Radiation and Climate at the University of Southern Queensland, Toowoomba, is to provide quantitative data on the solar UV environment and UV exposures to humans. The results presented at the conference show that as the solar zenith angle (SZA) of the sun increases so does the relative proportion of scattered UV beneath shade structures which in turn decreases the shade structures ultraviolet protection factor (UPF). The public shade structures used in my research are built to be effective in the middle of the day in summer when the sun is at its highest point. In an Australian winter, the erythemal UV in full sun can reach levels of approximately 2.5 MED/h (where a MED is defined as the minimum erythemal dose) or more in the middle of the day. Therefore, it is necessary for people that live in similar latitudes to minimise UV exposure in all climatic conditions throughout the year. Based on my research, a standard for reporting the UV protection provided by shade structures is essential for the public to make an informed decision on the efficacy of particular structures in reducing personal UV exposure.

David Turnbull

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How safe is a place in the shade?

POSTGRADUATE/DAVID TURNBULL

AUSTRALIA has the unenviable reputation of having one of the highest rates of mortality for skin cancer in the world. Skin cancer has been linked to excessive and repeated exposures to solar UV radiation, and causes more than 1000 deaths in Australia each year. The majority of these being preventable.

The role that solar UV radiation plays in the welfare of human beings is both good and bad, from helping bones absorb calcium more efficiently to the genesis of fatal skin cancers. As the public's understanding of the damaging effects associated with over-exposure to UV radiation increases, shaded environments will be sought to reduce personal UV exposure.

A common misconception is that shade protects the human body against all ultraviolet radiation. While direct UV from the sun is reflected or absorbed by the shade structure, the diffuse UV component is still present in the shade. Scattering of UV radiation by the atmosphere and the ground cover are the main causes of the diffuse UV. Over-exposure to this diffuse UV radiation may cause a number of conditions, particularly sunburn and eye damage.

Since beginning my research into the effects of UV radiation in 1999, I have been involved in various projects that have looked at such things as: UV exposure in tree shade, UV exposure in cars, and UV exposure to different anatomical sites on the human body. In 2001, I was given the opportunity, under the guidance of Dr Alfio Parisi, to complete a physics honours degree in solar UV radiation at the University of Southern Queensland. During this research I investigated the levels of UV radiation beneath various public shade structures, such as a common shade umbrella, a covered sand pit, a covered northern-facing veranda and a covered walkway. It was found that significant levels of diffuse UV radiation were prevalent in the shade, especially in winter.

Local governments provide many shade structures at parks and sporting ovals for public use. Therefore, the question remains as to how effective are public shade structures at reducing biologically effective UV radiation throughout the year? This question led to my beginning a PhD candidature in 2002, for which I decided to extend the scope of my research to include shade structures that are built by local councils and used throughout Australia and the world. My research has shown that there is generally more diffuse UV in the shade during the months of late autumn and early spring than in summer. Thus the public shade structures studied in the course of this investigation are likely to be at their most effective only in the middle of the day in summer, when the sun is at its highest point in the sky.

In September last year, I had the privilege of being able to present some of my findings to the international community at the 10th Congress of the European Society for Photobiology in Vienna. Delegates at the conference expressed to me their amazement at the levels of diffuse UV experienced in the shade in Australia.

During a winter in south-east Queensland, full sun UV radiation can reach levels of approximately a third or more of that registered in the middle of the day during summer. Therefore it is necessary for people who live in similar latitudes to minimise UV exposure under all climatic conditions throughout the year. The shade structures investigated in my research are simply inadequate for providing the public with sufficient year-long protection against damaging UV radiation.

"The message is that for long periods, shade alone does not provide enough protection from some biologically damaging UV"

When constructing shade structures, careful consideration must be given to these findings because, even though summer has the highest UV levels in the full sun, winter has the highest relative proportion of scattered UV in the shade due to the increased scattering resulting from the longer path of the solar UV through the atmosphere. Shade is certainly important as a UV minimisation strategy. However, the message is that for long periods, shade alone does not provide enough protection from some biologically damaging UV. Even though the UV transmission through the materials employed on the roof of the structures may be very low, it is the construction of the entire shade setting that determines the exposure beneath that structure. Shade structures that have trees, shrubs or buildings in close proximity generally have lower levels of UV in the shade than those having no such surrounding objects.

This particular research is only one of a number of projects undertaken in the University of Southern Queensland's Centre for Astronomy, Solar Radiation and Climate that aim to provide a greater understanding of the factors that influence solar UV exposures to humans.

■ David Turnbull is a PhD student at Centre for Astronomy, Solar Radiation and Climate, University of Southern Queensland.

Campus Review, vol. 14, no. 12, pp. 9.

Measuring the diffuse component of solar UV beneath shade structures: a practical activity for an Australian summer

by D.J. Turnbull and A.V. Parisi

David Turnbull is a physics PhD student at the University of Southern Queensland (USQ). His main area of research is on the interaction of scattered UV with different shaded environments and how this relates to human exposure.
Alfio Parisi is a senior lecturer in the Faculty of Sciences, at the University of Southern Queensland. His research projects have developed techniques to quantify the ultraviolet radiation exposure to both humans and plants under different conditions.

This article presents an investigation to provide students with the opportunity to study the physics of electromagnetic radiation, particularly UV radiation, and the way it interacts with different environments. The protective ability of shade structures is generally misunderstood, and this investigation will give students the basic knowledge that, even though shade structures protect the human body from direct UV radiation, it is now the diffuse UV radiation that is significant in the shade.

Introduction

Solar UV radiation plays a significant role in the development of life on this planet. UV radiation is both good and bad for humans, from helping to initiate the formation of vitamin D to increasing the risk of skin cancer and sun-related disorders (Turnbull, Parisi and Sabburg, 2003). The ultraviolet radiation waveband is broken into three sections: UVC (200 – 280 nm), UVB (280 – 320 nm) and UVA (320 – 400 nm). These sections comprise only a very small amount of the total incident solar flux (approximately 8.3%) (Simon, 1997). All of the UVC and most of the UVB is unable to penetrate the atmosphere due to attenuation. Attenuation occurs when the incident radiation is scattered and absorbed by molecules in the different layers of the atmosphere (Parisi and Kimlin, 1997).

As our understanding of the damaging effects associated with overexposure to UV radiation has grown, so we increasingly used shaded environments to reduce personal UV exposure. It is a common misconception that shade completely protects the human body against ultraviolet radiation. Because of atmospheric scattering (Rayleigh and Mie scattering), UV radiation is incident in two components, direct and diffuse (Turnbull, Parisi and Sabburg, 2003). Rayleigh scattering is associated with scattering by atmospheric gas molecules, the amount of scattering is inversely proportional to the fourth power of the wavelength of the radiation ($\propto \frac{1}{\lambda^4}$). Simply put, the shorter the wavelength, the higher the scattering. Mie scattering occurs when the wavelength of the incident radiation is similar in size to that of the scattering particles ($\propto \frac{1}{\lambda}$). While direct UV from the sun is generally reflected or absorbed by a shade structure, the diffuse component is still capable of affecting the body. This diffuse component is mainly due to atmospheric scattering (Toomey, Gies, and Roy, 1995). Although atmospheric scattering is the main cause of the diffuse component, other factors influence the amount of UV radiation that exists in the shade. These include clouds, air pollution, ozone levels, surface reflectivity, and seasonal and geographical variation.

The protective ability of a shade structure is referred to as its Ultraviolet Protection Factor (UPF). The UPF of a shade structure or material is analogous to the Sun Protection Factor (SPF) of a sunscreen, and the higher the better. The more sky that can be seen in the shade produced by the structure means the more scattered UV radiation is incident in the shaded area. The biological effectiveness of incident UV radiation is dependent on the radiation wavelength, because some wavelengths are more effective in being absorbed by macro molecules. The erythemal (sunburn) response of humans to UV radiation is given by the erythemal action spectrum (Figure 1). This investigation will give students the opportunity to measure erythemal UV radiation in full sun and in the shade. From this they can calculate each shade structure's UPF.

The intended outcomes of this investigation

The specific outcomes of the investigation are that students will:

1. gain an understanding of the basic physics principles involving solar radiation, especially UV radiation.
2. develop skills related to measuring solar UV radiation in full sun and in shade.
3. gain an understanding of the effect on humans of scattered UV radiation.

You will need

- A hand-held UV radiometer that uses specific filters to approximate the human erythemal response (CIE, 1987). A cost effective model is the *SafeSun* Classic model available from Optix Tech Inc, 1050 17th Street, NW, Suite 1150, Washington, DC 20036 at a cost of approximately AU$200.
- A lux meter that measures the intensity of the visible radiation waveband and can respond to visible radiation approximating the average human eye. A typical model is available from Dick Smith's Electronics for around $50.
- A thermometer or thermocouple device.

Measuring UV radiation

The protection offered by different shade environments is called the Ultraviolet Protection Factor (UPF). This is analogous to the Sun Protection Factor offered by sunscreens. The higher the UPF value, the better. UPF is defined by the following:

$$UPF = \frac{UVBE}{UVBE_s}$$

where UVBE is the erythemal UV in full sun on a horizontal plane and $UVBE_s$ is the erythemal UV in the shade on a horizontal plane. The shade ratio for each structure or material can also be calculated by simply inverting the above equation.

Pick three or four different commonly used shade environments. Choose a cloud-free bright sunny day for this investigation. To investigate the effect of the different angles of the sun on the UV radiation in the shade and the resultant UPF, take following measurements in the morning, for example 9.00 am, and again at midday.

To measure the UVBE:

1. Set the radiometer at about chest height in the shade.
2. Make sure the radiometer is in the centre of the shade and make sure that it is horizontal with the sensor facing up.
3. To reduce any obstruction to incident scattered UV, stay on the side with the least amount of visible sunlight.
4. Immediately after making the shade measurement, measure the UVBE in the full sun as far away from any structures or vegetation as possible.
5. Repeat the measurements for the other shade structures.
6. Measure the visible illumination levels on the horizontal plane with the lux meter in the middle of the shade.
7. Measure the ground level temperature with the thermometer in the shade and then in the full sun.
    - Calculate the UPF, erythemal UV shade ratio and lux shade ratio for each shade structure for the morning and noon measurements.
    - Compare the lux and UV shade ratios for different temperature ranges (e.g. 20-22°C, 22-24°C, etc).
8. Repeat the investigation on a cloudy day.

Table 1. ***Sample of results for the three shade structures showing UV levels in the shade and full sun, with calculated UPFs and shade ratios.***

		Erythemal UV			
Structure	Time	Shade	Sun	UPF	Ratio
Umbrella	9 am	0.38	0.58	1.5	0.67
	Noon	0.34	0.91	2.7	0.37
Gazebo	9 am	0.29	0.58	2.0	0.50
	Noon	0.26	0.91	3.5	0.29
Veranda	9 am	0.22	0.58	2.7	0.38
	Noon	0.24	0.91	3.8	0.26

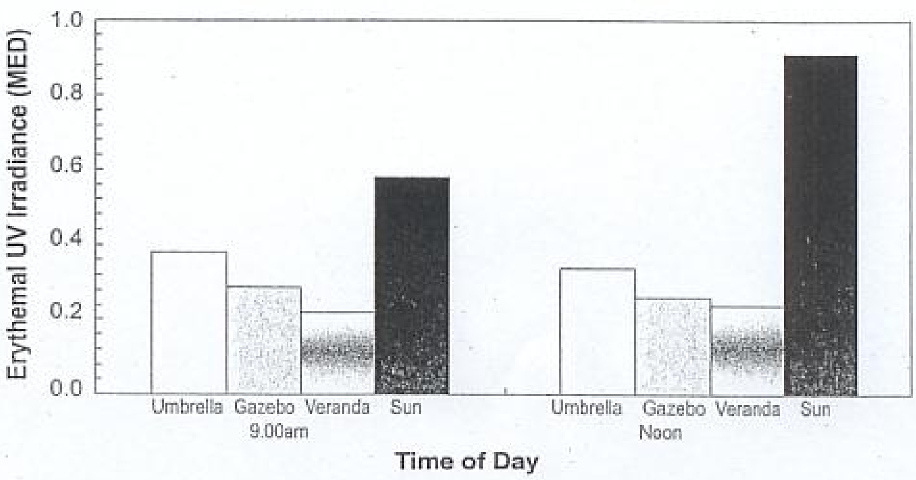

Figure 2. ***Sample results of the erythemal UV irradiances in the shade of three different shade structures and in full sun for both times of day.***

Table 2. *The illumination and temperature levels in the shade and in the full sun for all structures and both times of day.*

		Illumination (lux)			Temperature (°C)	
Structure	Time	Shade	Sun	Ratio	Shade	Sun
Umbrella	9 am	14000	86400	0.16	20	25
	Noon	8900	132000	0.07	24	30
Gazebo	9 am	6500	87000	0.07	21	25
	Noon	4400	134000	0.03	25	30
Veranda	9 am	4500	87500	0.05	21	25
	Noon	4300	135000	0.03	25	31

A sample results set: a basis for discussion

Table 1 and Figure 2 show a sample of results. The units of erythemal UV irradiance are based on the meter readings with the meter reading between 0 and 99 MED, with 1 MED corresponding to approximately 210 J/m^2 of erythemal UV. An MED is described as the minimum exposure to UV radiation required to cause erythema. The shade ratios in Table 1 show that there is a higher proportion of erythemal UV radiation in the shade for the morning measurements when compared to the noon measurements. This is due to the higher amount of scattering that occurs at the larger solar zenith angles. This increase in proportion of scattered UV in the shade equates to a decrease in the UPF of the shade structure.

Table 2 gives sample results for illumination and temperature levels in full sun and in the shade for both times of day. The ratio of the illumination levels in the shade of the shade structures compared to full sun is less than the shade ratio for the erythemal UV radiation. This is a direct result of Rayleigh scattering. Because visible radiation has a much longer wavelength than the radiation associated with erythemal UV (refer to Figure 1), there is less visible radiation in the shade.

The illumination and temperature levels in the shade are no indication of the erythemal UV levels in the shade. What humans feel as heat when they stand in the sun is the infrared radiation reacting with the skin. People can still be burnt on a cold, cloudy day.

The implications of this investigation

Australian schools provide many different forms of shade for their students to use during their breaks, but generally little is known about the effects of scattered UV in the shade. Erythemal UV in full sun during winter can still be high enough to cause sunburn and research has shown that erythemal UV beneath a public shade structure was up to 65% of that in full sun (Turnbull, Parisi and Sabburg, 2003).

Students completing this investigation will gain knowledge about the energy of electromagnetic radiation, its variation with wavelength, scattering of electromagnetic radiation and diffuse ultraviolet radiation. By bringing this aspect of the realities of an Australian summer (or winter) into the classroom, students will better understand the importance of physics to life.

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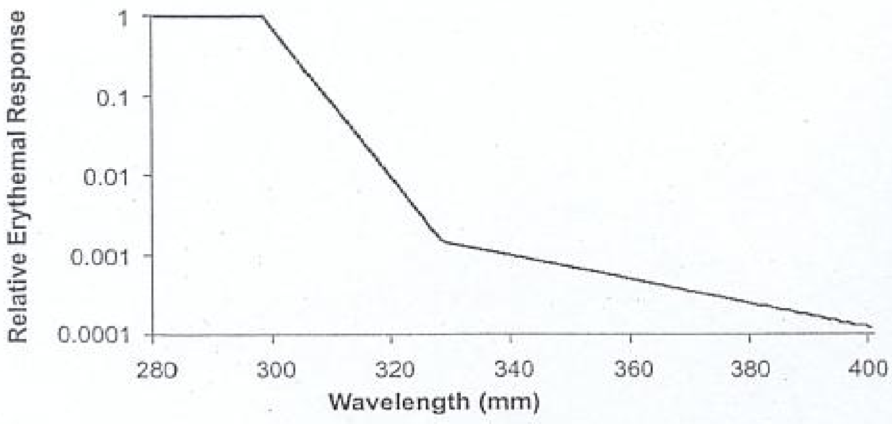

Figure 1. *The human erythemal action spectrum (CIE, 1997). The normalized relative effectiveness of the UV spectrum to cause sunburn.*

WARNING

This investigation will require that you spend extended periods outdoors. Use appropriate sun protection strategies such as sunscreen, hats and sunglasses to reduce your personal UV exposure.

Appendix E

Conferences and Media

UV Protection and Shade Structures

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Abstract
Broadband field measurements were conducted beneath three different sized public shade structures at a sub-tropical Southern Hemisphere site for relatively clear skies and for a changing solar zenith angle (SZA) of 13^o to 76^o. These data were compared to the diffuse UV to quantify the relationship between diffuse UV and the UV in the shade of the structures. On the horizontal plane, the ultraviolet protection factors (UPF) for the shade structures ranged from 1.5 to 18 for a decreasing SZA. The data from this research is significant, because it shows that as the SZA of the sun increases so does the relative proportion of scattered UV beneath the shade structures which in turn decreases the shade structures UPF. In Australia, erythemal UV in full sun can reach levels of approximately 2.5 MED/h or more in the middle of the day during winter. Therefore, it is necessary for people that live in similar latitudes to minimise UV exposure in all climatic conditions throughout the year. Based on this research, a standard for reporting the UV protection provided by shade structures is essential for the public to make an informed decision on the efficacy of particular structures in reducing personal UV exposure.

Presented at the 10th Congress for the European Society for Photobiology, Vienna, Austria, 6-11 September 2003.

David Turnbull (USQ):

"The Protective Nature of Public Shade Structures in Australia"

The specific nature of the role that solar UV radiation plays in the welfare of human beings is both good and bad, from helping bones absorb calcium more efficiently to the genesis of fatal skin cancers. As the public's understanding of the damaging effects associated with over exposure to UV radiation increases, shaded environments will be sought to reduce personal UV exposure. Local governments provide many shade structures at parks and sporting ovals for public use. However, the question remains of how effective are public shade structures at reducing biologically effective UV radiation throughout the year? In Australia, erythemal UV in full sun can reach levels of approximately 2.5 MED/h (where an MED is defined as the minimum erythemal dose) or more in the middle of the day during winter. Therefore, it is necessary for people that live in similar latitudes to minimise UV exposure in all climatic conditions throughout the year. Based on this research, a standard for reporting the UV protection provided by shade structures is essential for the public to make an informed decision on the efficacy of particular structures in reducing personal UV exposure.

Presented at the AIP Branch meeting at Griffith University, Postgraduate Seminar Evening, 21st October 2003.

UV PROTECTION PROVIDED BY PUBLIC SHADE STRUCTURES DURING WINTER

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Purpose of study: As people become more aware about the damaging effects of UV radiation, they will seek shaded environments to reduce their personal UV exposure. Although shade does decrease direct UV, it is the diffuse UV that can still have significant levels in the shade. At this point in time very little is known about how UV radiation interacts with shade structures during winter. Broadband UV irradiance measurements in the field were conducted beneath three different sized public shade structures, small, medium and large. This research compares the scattered UV levels beneath these specific shade structures, built by the local council, with that of the diffuse UV on an unshaded horizontal plane for clear skies at a sub-tropical Southern Hemisphere site during winter. The data gathered is significant, because the relative proportion of scattered UV in shade is at its greatest for the higher solar zenith angles seen during winter.
Conclusions: The public shade structures used in this research are built to be effective in the middle of the day in summer when the sun is at its highest point. In Australia, erythemal UV in full sun can reach levels of approximately 2.5 MED/h or more in the middle of the day during winter. Therefore, it is necessary for people that live in similar latitudes to minimise UV exposure in all climatic conditions throughout the year. These specific shade structures are inadequate for providing the public enough protection against damaging UV radiation.

Presented at the Queensland Health and Medical Scientific Meeting, Brisbane, 25-26 November 2003.

IMPROVING THE PROTECTIVE EFFICIENCY OF SHADE STRUCTURES

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Scattered UV radiation is present underneath shade structures due to scattering by the atmosphere and surroundings. Therefore, 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 as a result of using two types of side-on protection, namely, polycarbonate sheeting and vegetation. Anatomical facial dosimetry measurements conducted in the shade of a scale model shade structure during summer and winter showed significant decreases in UV exposure for summer and for winter when polycarbonate sheeting was added to specific sides of the shade structure. Broadband field measurements conducted in the shade of four shade structures with various amounts of vegetation covering different sides, showed that the positioning of vegetation for side-on protection is vital for decreasing the scattered UV in the shade. 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 itself 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.

Presented at the 14th International Congress on Photobiology, Jeju, South Korea, 10-15 June, 2004.

Improving the Protective Efficiency of Shade Structures

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Introduction

Scattered UV radiation is present underneath shade structures due to scattering by the atmosphere and surroundings. Therefore, 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. 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 minimisation strategy due to the considerable amount of scattered UV prevalent in the shade. Also, at certain times of the day, the shade is not always beneath the shade structure [1].

Methodology

UV exposures were assessed for the decrease in scattered UV beneath specific shade structures as a result of using two types of side-on protection, namely, polycarbonate sheeting and vegetation (see Figure 1 and 2). Three types of polycarbonate (PC) sheeting were considered based on the ability to significantly reduce UV transmission but also to transmit as much visible and infrared radiation possible.

Figure 1 - the half-size scale model with the clear tint polycarbonate sheeting attached to two sides. Manikin headforms with polysulphone dosimeters attached to various facial sites are situated in the centre of the structure and in full sun.

Conclusions

Anatomical facial dosimetry measurements conducted in the shade of a scale model shade structure during summer and winter showed significant decreases in UV exposure for summer and winter when polycarbonate sheeting was added to specific sides of the shade structure. Decreases in exposure of almost three and a half times for summer and up to two times for winter when comparing the use and non-use of polycarbonate sheeting.

Broadband field measurements conducted in the shade of four shade structures with various amounts of vegetation covering different sides, showed that the positioning of vegetation for side-on protection is vital for decreasing the scattered UV in the shade.

Adding suitable vegetation and/or polycarbonate sheeting to specific sides of shade structures can 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.

Results

Exposure ratios to the eyes, nose, forehead and cheeks in the shade with the use of PC sheeting were up to three and a half times less than the shade exposures with no PC sheeting during summer. The PC sheeting had slightly less of an effect on erythemal UV exposures during winter, with exposure ratios of just over two times less than compared to no PC sheeting.

Table 1 - summary of anatomical facial distribution of exposure ratios beneath the model shade structure for summer and winter.

	Summer (exposure ratios)				Winter (exposure ratios)			
Facial Site	No PC	Bronze	Grey	Clear	No PC	Bronze	Grey	Clear
forehead	4.0	2.2	1.5	2.4	5.6	3.7	2.5	4.5
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
eyes	4.2	2.3	1.9	2.9	5.0	4.2	4.5	4.0

Broadband field measurements beneath the four shade structures (shown in Figure 2) reveal that adding appropriate vegetation to two specific sides of a structure can significantly reduce exposure levels in the shade of the structure.

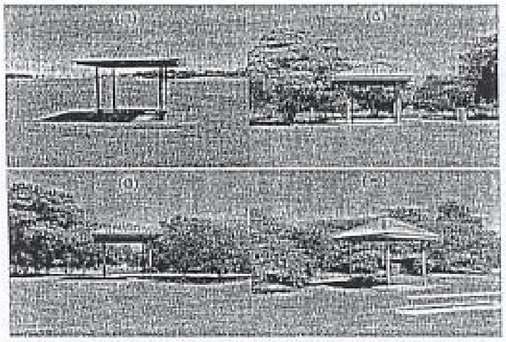

Figure 2 - the four shade structures used with varying levels of surrounding vegetation.

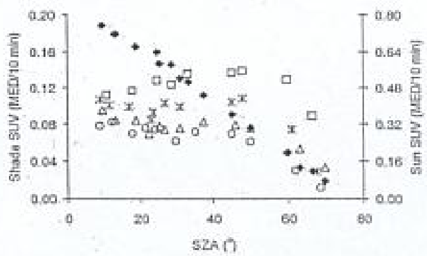

Figure 3 - maximum SUV exposures observed beneath the four shade structures (shown in Figure 2) compared to full sun (♦).

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