SPECTRAL ULTRAVIOLET ALBEDO OF ROOFING SURFACES AND HUMAN FACIAL EXPOSURE

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Running Title: UV Albedo of Roofing Surfaces

Abstract

Spectral field measurements were used to quantify the ultraviolet (UV) spectral albedos of four different metallic roofing surfaces. The effect of the albedos of two of these surfaces on erythemal exposure to human facial anatomical sites was quantified by UV dosimetry. The albedos of all roofing surfaces were greater than the albedo of grass. Little SZA dependence was observed for any of the surfaces. The albedos of the coloured metallic corrugated surfaces were strongly dependent on wavelength in the UVA, increasing from 3 to 12%. Facial erythemal measurements showed significant exposure enhancements over the galvanised corrugated surface compared to grass. The undersides of the chin and nose received exposure enhancements over the galvanised corrugated surface of about 1290% and 190% respectively, of the exposure of these sites over grass. It is concluded that the albedo of the galvanised surfaces are higher than those of the coloured surfaces by at least 20%, and higher than grass by at least 27%. Consequently, normally shaded facial anatomical sites receive substantially higher UV exposures over these galvanised surfaces compared to grass.

Introduction

UV radiation is known to cause skin cancer (Longstreth **et al**. 1995) and eye diseases (Sliney 1999) in humans. The effectiveness of biologically active radiation in causing such diseases depends on the intensity and wavelength of the radiation. The spectral intensity may be enhanced by UV reflected and scattered from a roofing surface (McKenzie **et al**. 1996). Variations of spectral irradiance resulting from such diffusion, therefore affect the biologically active radiation over roofing surfaces. Quantification of such variations is required in order to assess the risk of skin and eye diseases for those such as builders, plumbers and painters who spend substantial amounts of time working over these surfaces.

The surface albedo is defined as the ratio of ambient downwelling irradiance to upwelling irradiance over a horizontal surface (McKenzie **et al**. 1996). The albedo thus provides a method for quantifying the enhancement of UV radiation over a roofing surface. Different roof angles may be accounted for by quantifying the albedo as a function of solar zenith angle (SZA).

Previous field research has quantified the spectral albedo of grass (McKenzie **et al**. 1996) and snow (McKenzie **et al**. 1998), and the broadband erythemal albedos of various surfaces, including a butyl rubber roof have been determined (Blumthaler and Ambach 1988). However, to the authors' knowledge the spectral albedo of galvanised and coloured metallic roofing surfaces have not previously been determined. Nor have erythemal exposure enhancements due to the effect of albedo been determined.

The albedos of galvanised (shiny silver) corrugated, dark-green and pale-pink metallic corrugated surfaces were investigated in this research. The effects of the albedos of the galvanised and dark-green surfaces on human erythemal facial exposure were also quantified.

Materials and Methods

Roofing Surfaces

Good-condition and un-aged sheets (seconds) of galvanised corrugated, dark-green and pale-pink metallic corrugated roofing surfaces were employed in this research. The corrugations of all surfaces were symmetrical with a trough to peak height of 18 mm and separated by 75 mm. The albedo measurements took place in an open field in Toowoomba, Queensland (27°36' S, 151°55' E) over a roofing surface area of 3 × 3 m that was laid horizontally on the ground. The corrugations and ridges were aligned parallel to the east-west direction for all measurements.

Spectroradiometry

The upwelling and downwelling irradiances used to determine the spectral albedo of the roofing surfaces were measured with a spectroradiometer, which employs a 15 cm diameter rotatable integrating sphere (model OL IS-640, Optronics Laboratory, Orlando, USA). The dispersion unit comprises a concave double holographic grating UV monochromator with 1200 lines per millimetre (model DH10, Jobin-Yvon Co., France) which is connected to an R-212 photomultiplier (Hamamatsu Co., Japan), temperature stabilised to 15° ± 0.5°.

The spectroradiometer was calibrated for wavelength against the 365 nm emission line of mercury. The irradiance was calibrated against a quartz-tungsten halogen secondary standard lamp with a calibration traceable to the CSIRO National Standards Laboratory, Lindfield.

The integrating sphere was positioned centrally over the roofing surface at a height of 1.7 m and 4 sequential scans were performed, each taking about 1 minute. The aperture of the integrating sphere was zenith-aligned for the first and fourth scans, measuring downwelling irradiance. The estimated obstruction to the downwelling irradiance by the spectroradiometer was about 0.37°. The downwelling scans were averaged to correct for the change in SZA during the time required for the 4 scans. The aperture was nadir-aligned for the second and third scans. These two upwelling scans were averaged to improve the signal to noise ratio of the upwelling irradiance.

The total UV, UVA and UVB broadband albedos were calculated from the ratio of upwelling to downwelling irradiance, which were each determined by

$$UV_{BB} = \int_{\lambda_1}^{\lambda_2} S(\lambda) d\lambda$$

where UV_{BB} is the broadband irradiance, $S(\lambda)$ is the spectral irradiance measured by the spectroradiometer, $d\lambda$ is the wavelength increment, λ_2 = 400 nm and λ_1 = 280 nm for the calculation of total UV irradiance, λ_1 = 280 nm and λ_2 = 315 nm for that of the UVB, while λ_1 = 315 nm and λ_2 = 400 nm for that of the UVA (Kimlin and Parisi 1998). Similarly, the biologically weighted albedos were calculated from the respective upwelling to downwelling irradiance ratio. These irradiances were determined from

$$UV_{BE} = \int_{UV} S(\lambda) A(\lambda) d\lambda$$

where UV_{BE} is the biologically effective UV, $S(\lambda)$ is the spectral irradiance measured by the spectroradiometer, and $A(\lambda)$ is the action spectrum for the biological response of interest (Parisi **et al**. 1999).

UV Radiation Dosimetry

Rectangles (12 × 16 mm) of polysulphone (Diffey 1989) were supported by cardboard windows (30 × 30 mm) forming UV radiation dosimeters that were affixed to various anatomical sites of 3 manikin head-forms. The head-forms were placed in an upright position, 95 cm (at eye level) above the ground, and were rotated by 90° every 15 minutes. The first head-form was placed over the galvanised surface, the second over the dark-green metallic surface, and the third over grass.

The optical absorbencies of the polysulphone dosimeters were measured with a Shimadzu UV (model 1601) spectrophotometer before and after exposure of the dosimeters on the head-forms. The change in absorbency due to UV radiation exposure was related to the time integrated erythemal exposure by calibrating the dosimeters against a temperature-stabilised biometer (model 501, Solar Light, PA). The absorbency measurements of both the calibration and experimental dosimeters were made at least 24 hours after the exposures to reduce the effect of the dark reaction of polysulphone (Diffey 1989).

Results

Spectral Albedo

The mean of ten spectral albedo measurements of the galvanised and pale-pink surfaces between 21° and 43° SZA determined in spring are shown in Figure 1. The mean albedo of the galvanised surface was 27% at 305 nm and increased to 30% at 400 nm. The albedo of the pale-pink surface ranged from about 4% between 305 and 350 nm, to 11% at 400 nm within the same SZA range.

SZA Dependence

The total UV albedo of the galvanised corrugated surface remained in the 20 to 30% range, with a slight decreasing trend between 37.8° and 59.5° SZA. An increasing trend was observed at larger SZA between 59.5° and 70.3°. These trends were slight (<5%) and would have little influence on the biological effects resulting from albedo.

Broadband and Biologically Weighted Albedo

The broadband UVA albedo of the galvanised surface was 29 ± 3% with changing SZA from 21° to 43°. The UV albedo was identical to the UVA albedo within 0.1%. The broadband UVB albedo was about 1.5% less than the UVA. Those weighted against the erythemal (CIE 1987), DNA damage (Caldwell **et al**. 1983), photoconjunctival (CIE 1986a), photokeratitis (CIE 1986b), and the actinic (IRPA 1989) action spectra were within 0.6% of the UVB albedo over this SZA range.

The broadband UV albedo of the pale-pink surface remained within 0.1% of the UVA albedo varying between 5 and 6% over the 21° to 43° SZA range. The biologically weighted albedos were within 0.3% of the UVB, and the UVB and biologically weighted albedos remained about 2% lower than that of the UVA.

A winter comparison of the broadband and weighted UV albedos of the galvanised surface is shown in Figure 2. The UVA albedo was about 25% over a SZA range of 44° to 63°. The UVB was about 8% lower at 63°, whereas at 55° it was equal to the UVA. The weighted albedos were nearly identical to those of the UVB at SZA less than 59°. At larger SZA however, the albedos of the weighted responses were lower than that of the UVB. The albedo of the responses with greater weightings in the UVB decreased more rapidly with decreasing SZA between 59° and 63° (Figure 2).

Product Comparison

Four different roofing surfaces were compared with grass within 14.2° SZA during winter. The weighted albedo of the grass ranged from 1 to 3%. The albedos of the metallic coloured surfaces were higher, ranging from 3 to 12% depending on the surface colour and on wavelength. The albedo of the galvanised surfaces remained at about 30% over the UV waveband. The biologically weighted albedos of the coloured metallic surfaces ranged from 3 to 6%, while those of the galvanised surfaces were substantially higher, ranging from 25 to 32%.

The erythemal exposures of various anatomical sites of the human head-form during a 6-hour autumn period are shown in Figure 3. An ambient exposure of 13.4 MED (minimum erythemal dose) was observed during this period where 1 MED is defined as 200 Jm^{-2} (Diffey 1992). The exposure enhancement under the chin was 1286%. Significant enhancement occurred also for the underside of the nose and the cheeks of around 190% and 140% respectively.

Discussion

The spectral UV albedos of all roofing surfaces were not influenced significantly by SZA. Small UV enhancements of up to 3% compared to grass were observed over the pink and green surfaces, while the albedos of the galvanised surfaces were higher than that of grass by at least 27%.

The albedo dependence of the pink metallic surface on wavelength was strong in the UVA waveband at wavelengths longer than 360 nm, resulting in enhancements of up to 11%. The albedos of the corrugated surfaces were independent of wavelength, remaining at about 30% over the entire UV waveband. These albedos are high compared to the albedos of many other surfaces reported in the literature, except for snow (McKenzie **et al**. 1996) and possibly beach sand.

The UVA enhancement over these surfaces, especially the galvanised surfaces, increases the risk of chronic diseases such as photoaging and cutaneous malignant melanoma, which are related to exposure to this waveband. The UVB albedo was only about 2% lower than the UVA albedo for both the coloured metallic surfaces and the galvanised surfaces. Therefore, the efficiency of reflection and scattering of UVB from these surfaces is almost the same as that of the UVA. The intensity of solar UVB is about 100 times less than that of UVA, however the biological effectiveness is some 1000 times greater. The biological effects of enhanced UVB due to surface albedo are therefore significant. This is especially true for the galvanised surfaces, with UVB enhancements of around 30%.

The biologically weighted albedos measured in spring were essentially the same as the UVB albedos. This indicates that radiation active in causing erythemal, actinic, DNA damage, photoconjunctival and photokeratitis responses are enhanced by about 30% over the galvanised surfaces. A sharp decrease in the UVB and weighted albedos occurred at large SZA in winter.

Therefore, in terms of acute UVB responses, early mornings and late afternoons in winter may offer the safest conditions of UV exposure for working over galvanised roofing surfaces.

The shading effects of facial anatomy are evident in the dosimetry results. Over grass, upward oriented sites such as the vertex of the head and bridge of the nose received larger exposures than the shaded sites of the undersides of the chin and nose. The spectral measurements predict exposures over the galvanised surfaces of up to 27% greater than over grass for downward oriented sites parallel to the roofing surface. Dosimetric measurements made under the chin and under the nose support these predictions. These sites receive low UV exposures over grass due to anatomical shading and the low albedo of grass. Reflected and scattered UV resulting from surface albedo generally moves in an upward direction. The high albedo of the galvanised surfaces compared to grass therefore results in much greater exposures to the undersides of the chin and nose. Hats will not offer protection against this upwelling radiation.

Conclusion

The high albedo of the galvanised surfaces in both the UVA and UVB has salient implications for human health. If protective strategies are not employed for workers over these roofing surfaces, the reception of threshold doses for erythema, DNA damage, photoconjunctivitis and photokeratitis will be received in shorter exposure periods over galvanised metallic surfaces than coloured metallic surfaces and grass. Multiple episodes of these acute responses may lead to basal cell and squamous cell carcinomas of the skin, and eye diseases such as cataracts and pterygium. Photoaging and the risk of cutaneous malignant melanoma will also increase as a result of enhanced UVA. To a lesser extent, UVA related diseases will increase over dark-green and pale-pink metallic corrugated surfaces due to the enhanced UVA radiation resulting from the albedo of these surfaces.

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Figure Captions

Figure 1: (a) Mean spectral albedo of (a) the galvanised surface and (b) the pale-pink surface in spring, determined between 22° and 43° SZA.

Figure 2: (a) UVA, (b) UVB, (c) actinic, (d) DNA damage and the (e) photoconjunctival weighted albedo of the galvanised corrugated surface versus SZA in winter.

Figure 3: Six hour human facial erythemal exposure over grass, the dark-green metallic, and the galvanised surfaces in autumn.

Figures

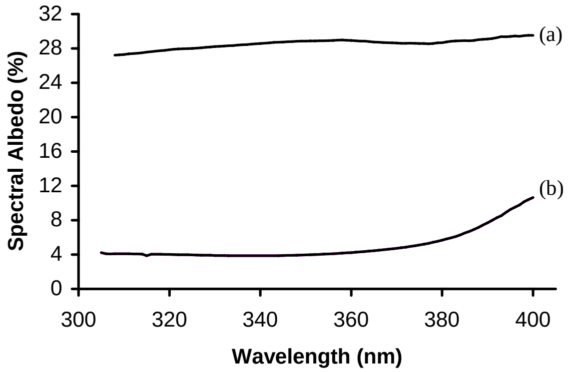
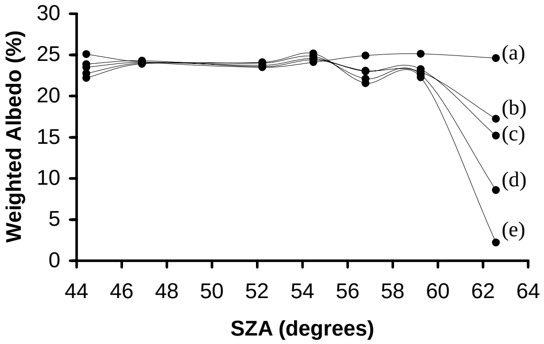


Figure 1



Weighted Albedo (%)
30
25
20
15
10
5
0
44
46
48
50
52
54
56
58
60
62
64
SZA (degrees)
(a)
(b)
(c)
(d)
(e)

Figure 2

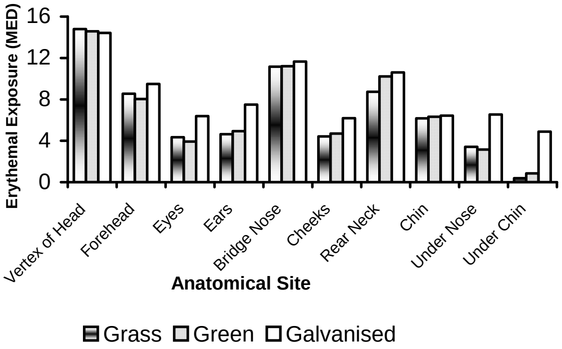

Erythemal Exposure (MED)
16
12
8
4
0
Vertex of Head
Forehead
Eyes
Ears
Bridge Nose
Cheeks
Rear Neck
Chin
Under Nose
Under Chin
Anatomical Site
Grass
Green
Galvanised

Figure 3