UNIVERSITY OF SOUTHERN QUEENSLAND

Ultraviolet radiation reflection from building materials:

Characterisation, quantification and the resulting effects

A dissertation submitted by

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Abstract

Ultraviolet (UV) radiation significantly influences many biological entities in the terrestrial biosphere. However, the amount of UV exposure can be affected by surfaces that reflect UV radiation. Knowledge about reflected UV radiation from surfaces in the built environment is limited, especially from vertical or other non-horizontal surfaces and the resulting effects of UV radiation reflection from these surfaces. The main aims of this research is comprised of (1) characterisation of UV radiation reflection from a variety of urban building materials in vertical positions, (2) quantification of the biological effect of UV reflection from simulated structures on a human and (3) establishing relationships between UV radiation measurement indicators and resulting biological effects.

UV radiation reflection was investigated using spectral measurements made with portable spectrometers, and took into consideration factors that could influence the measurements including orientation, direction, solar zenith and azimuth angles and surface type. The biological effects due to reflection from vertical urban structures were investigated using dosimetry which enabled body site UV exposure analysis. Relationships from UV radiation reflection between different surface orientations (vertical, horizontal and inclined) were quantified. The UV Index was used to predict changes to UV exposure from certain vertical UV radiation reflective surfaces.

Spectral reflection from vertical urban structures was found to be variable and for metallic surface types the variation appears to be predominantly controlled by solar zenith and solar azimuth angles, with man-made surfaces reflecting some radiation specularly. Hence, surface type and the coating on the surface type dictates the way UV radiation is reflected from a surface. Increases in UV exposure are observed during seasons with larger solar zenith angles, and decreases in seasons with

predominantly lower solar zenith angles. This produces an observable seasonal effect, creating a potential problem in cooler seasons than in warmer seasons due to human behaviour, where personal UV protection can be overlooked compared to thermal comfort. This study has shown that UV reflection from certain vertical surfaces will substantially enhance UV exposure to an individual, and reduce the time for an outdoor worker to exceed recommended UV exposure limits.

CERTIFICATION OF DISSERTATION

I certify that the ideas, experimental work, results, analyses, software 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.

________________________________ ________________

Signature of Candidate Date

ENDORSEMENT

________________________________ ________________

Signature of Supervisor Date

________________________________ ________________

Signature of Associate Supervisor/s Date

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List of Abbreviations

BCC	Basal cell carcinoma
DNA	Deoxyribonucleic acid
DT	Delayed tanning
FM	Frequency modulated
IPD	Immediate pigment darkening
OMI	Ozone monitoring instrument
NMSC	Non melanoma skin cancer
RB	Robertson-Berger
SAA	Solar azimuth angle
SCC	Squamous cell carcinoma
SZA	Solar zenith angle
UV	Ultraviolet
UVA	Ultraviolet (waveband) A
UVB	Ultraviolet (waveband) B
UVC	Ultraviolet (waveband) C

Glossary of frequently used terms

Action spectrum	A function that represents the effectiveness of each wavelength or interval in any part of or all of the solar electromagnetic spectrum at producing a photochemical or photobiological reaction.
Actinic keratosis	Excessive growth of skin layers (usually hard to the touch) from over-exposure to ultraviolet radiation.
Dose	Amount of radiation someone or something is exposed to (as in absorbed dose) measured in energy per unit area.
Dosimeter	A device that measures radiation exposure ("dose meter").
Dosimetry	The use of a device called a dosimeter to measure radiation exposure.
Diffuse (radiation)	Radiation that has undergone scattering, with longer path lengths than shortest path between a radiation source and a receiver, and can be incident from any direction.
Diffuse (reflection)	Radiation penetrating the boundary of a surface and undergoing reflection (via elastic collisions) by one or more particles or molecules, resulting in radiation leaving the surface independently of the angle of incidence.
Direct (radiation)	Radiation that travels in the shortest path possible between the radiation source and a surface or receiver.
Global (radiation)	Total radiation measured when a receiver is oriented on a horizontal surface, indicating that all radiation in the hemisphere above the receiver (direct and diffuse) is included in the measurement.
Erythema	Inflammation and oedema of the skin due to photochemical reactions caused by ultraviolet irradiance (commonly known as sunburn).
Irradiance	Total power of electromagnetic radiation per unit area of surface (measured in Watts per square metre where Watt is energy per unit of time).

Minimum erythemal dose

The smallest amount of erythemal ultraviolet radiation required for people with skin type I (fair skin) to cause barely perceptible erythema (equivalent on average to 200J/m^2).

Photokeratitis — Painful inflammation of the eye (specifically the cornea) due to over-exposure to intense or prolonged ultraviolet radiation exposure.

Radiation — (Electromagnetic) radiation is the energy produced by propagation of oscillating electric and magnetic fields due to accelerating electric charge.

Specular (reflection) — Radiation reflected at the immediate boundary of a surface, with the reflected angle dependent on the incident angle.

Solar zenith angle — The angle between the top of the celestial hemisphere and the position of the sun on the arc between the top of the sphere and the horizon (the top of the sphere is 0° and usually the horizon is 90°).

Solar azimuth angle — The angle the sun makes between true north and any point heading clockwise around the compass points (true north is 0° and becomes 360° after one full revolution around the compass points). In some cases negative values (0° to -90°) from true north might be used to keep all solar azimuth angles within the northern quadrants with measurements in the southern hemisphere.

Standard erythemal dose

An exact dose of 100J/m^2 of erythemal ultraviolet radiation.

Total (radiation) — Total radiation measured when a receiver is oriented on a plane that is normal to the radiation source, indicating that all radiation (direct and diffuse) in the path between source and the receiver is included in the measurement.

Ultraviolet (radiation) — Electromagnetic radiation that has specific a specific wavelength and frequency range. Ultraviolet radiation consists of waveband from 100 nm to 400 nm, with solar ultraviolet radiation consisting of 290 nm to 400 nm. Refer to Section 1.2.1.2 for further detail.

1 Introduction and Literature Review

1.1 Introduction

In the field of ultraviolet (UV) radiation monitoring and UV dose exposure measurement, the ability to account for factors that influence these measurements is becoming more and more important. The importance of this knowledge is dictated by the need for better understanding of the effects of UV radiation in the biosphere (Blumthaler 1993; Seidlitz & Krins 2006). Cohen (2003) predicted some years ago that more than half of the population of the world will live in cities by the end of this decade. We are now at that point in the decade and while this number has not yet been confirmed, it is accepted that the majority of the world's population now live in or near urban centres. Therefore, measurement in UV radiation and dose monitoring should be taking into account factors specific to urban environments, yet the body of knowledge on this topic, specifically that on reflective surfaces in vertical structures remains small.

Terrestrial UV radiation is highly variable and significantly affects a variety of biological entities in a variety of ways (Caldwell et al. 2007). Because of this reason it is imperative to be able to acquire accurate measurements of instantaneous and average UV irradiance and exposure (Seidlitz & Krins 2006) in order to understand effects on the biosphere. The variety of effects on biological entities from UV radiation is a result of the range of energies that it encompasses in the electromagnetic spectrum, to the point that it can behave as both ionising and non-ionising radiation (depending on what it is interacting with). While the ionising effect of UV radiation is retained to upper atmospheric locations, the effect of non-ionising UV radiation reaching the earth's surface can be both beneficial and harmful biologically, where the harm involved often outweighs the benefits when exposure times are increased. The biological effects of UV radiation is a large research area, but the influencing factors affecting UV radiation fluctuation in an urban setting, which is where a significant proportion of the population dwells, is not so well understood. In order to be able to take preventative action against harmful biological effects of UV radiation on humans, this influence of urban factors needs to be researched.

Those most affected by UV radiation in their lifetimes, are people who spend their working hours outdoors. In particular, workers in the construction industry, who handle UV reflective surfaces, will be most prone to UV radiation effects on their health. In order to advise such workers on preventative measures from excessive UV exposure in these situations, it is necessary to quantify the effects of UV radiation reflective surfaces and resulting exposures. In addition, modellers who seek to predict UV radiation levels in urban environments will be able to incorporate this information in order to improve the resulting models. At the same time, an attempt to better understand the interactions between UV radiation and UV reflective surfaces will be conducted, so that choices in selecting building materials that are dependent on UV reflectivity can be made if necessary.

1.2 Literature Review

1.2.1 Ultraviolet radiation

1.2.1.1 Electromagnetic radiation

The terrestrial environment is bombarded by electromagnetic radiation emanating from the sun. In fact, the earth would be unlikely to be in its present state ecologically and environmentally, if the sun did not emit electromagnetic radiation. UV radiation penetrating the early earth’s atmosphere, was specifically involved in the photo dissociation of water vapour releasing oxygen into the atmosphere (Tevini 1993) around two billion years ago. This reaction (as well as many other photochemical reactions) resulted in chemical compounds important to the development of life. According to classical physics, electromagnetic radiation is defined as the "energy resulting from the acceleration of electric charge and the associated electric fields and magnetic fields" (Isaacs 1996). Electromagnetic radiation is thus a form of energy and can be described conceptually and mathematically as a self propagating wave of oscillating electric and magnetic fields. Modern physics dictates that electromagnetic radiation can also be understood in terms of photons, which are discrete quantities of energy with particle characteristics. The energy of electromagnetic radiation is defined quantitatively as $E = hf$ where f is defined as the frequency of the wave of the electromagnetic radiation and h is Planck's constant. Using the classical characteristics of a wave, the frequency of a wave is inversely proportional to its wavelength (λ) and together is related by the speed of the wave. The speed of electromagnetic radiation in a vacuum is constant ($c = 2.998\times10^{8}\mathrm{ms}^{-1}$) and thus the relationship is $c = f\lambda$. It stands to reason that simple substitution of this latter equation into the former can show the dependence of energy of electromagnetic radiation on the characteristic wavelength as $E = \frac{hc}{\lambda}$. Electromagnetic radiation energy can be referred to by its characteristic wavelength or frequency. In UV radiation research, the energy involved is described using wavelength, as used in Parisi, Sabburg & Kimlin (2004a).

Solar electromagnetic radiation is made up of UV radiation, visible radiation and infrared radiation, which is the only electromagnetic radiation to reach the earth's surface. The sun emits electromagnetic radiation that is dependent on its temperature, according to Planck's Law (Webb 1998b). In fact a plot of intensity per unit wavelength versus wavelength of the solar output (Webb 1998b) resembles black body radiation curves (Serway, Moses & Moyer 1997) and when plotted for the temperature of the sun and compared to intensity of spectral irradiance at the top of the atmosphere only vary by small amounts (Lenoble 1993a). As a result of these solar emissions, the peak wavelength emitted is found in the visible part of the solar spectrum, but the emission curve reaches to as low as 200 nm and as high as 3000 nm, hence the spectrum reaches to the lower and upper regions of the ultraviolet and infrared wavebands. This range is applicable to radiation at the top of the earth’s atmosphere. As the electromagnetic radiation travels through the earth’s atmosphere, it is attenuated. The various mechanisms involved in the attenuation of the solar radiation will be discussed later in this thesis.

Evolution has led to human eyesight matched to the narrow visible spectrum in which solar radiation is the most abundant, whilst our bodies can feel infrared radiation as heat. On the other hand, UV radiation cannot be immediately detected, leaving humans with biological mechanisms that have only delayed responses. So despite the fact that UV radiation is the most damaging biologically of all the solar radiation received at the earth’s surface, our bodies have no immediate way to sense it. Therefore, we must devise alternate ways to detect and measure UV radiation in order to understand its influences on biological mechanisms.

1.2.1.2 Ultraviolet radiation spectrum

UV radiation reaching the earth’s surface is non-ionising radiation (WHO 1994) which is radiation that does not cause the production of ions when passing through matter (Ng 2003; Sliney & Chaney 2006). The entire UV spectrum is designated as the waveband from 100 nm to 400 nm where the lower boundary is also taken as the boundary between ionising and non-ionising wavelengths. However, due to the atmosphere's attenuation, not all UV radiation reaches the earth's surface, and therefore the UV spectrum is further divided. The spectrum was first divided into the following wavebands and respective names:

UVC - 100 nm to 280 nm

UVB - 280 nm to 315 nm

UVA – 315 nm to 400 nm

Although these divisions were made arbitrarily at the Second International Congress of Light in 1932 (Diffey 2002b), the literature review presented here suggests that the divisions were the result of some initial understanding of spectral biological effectiveness. Today, as Diffey (2002b) points out, the wavebands of interest are dependent on the principle research area involved and may change accordingly, for example, environmental and dermatological photobiologists use the following divisions:

UVC – 100 nm to 290 nm

UVB – 290 nm to 320 nm

UVA – 320 nm to 400 nm

The latter set of divisions is dependent on the shortest wavelength reaching the earth's surface (around 290 nm), whereas the boundary between UVB and UVA is more arbitrary. However, the problem with this is that the solar UV spectrum cut-off varies seasonally (Kollias, Baqer & Ou-Yang 2003), which means that using a spectrum that discounts some wavelengths may adversely affect year round measurements. While Kerr (2003) states that the short wavelength cut-off depends on atmospheric ozone (indicating that the short wavelength cut-off can be monitored), it makes more sense to follow the advice of Sliney (2007) who recommends adhering to the original divisions in the UV spectrum in order to maintain a consensus between disciplines and therefore some comparability (the former presented waveband divisions).

At the top of the atmosphere, UV radiation only accounts for between 8 to 9 % of all solar radiation with UVC, UVB and UVA comprising 0.5%, 1.5% and 6.3% respectively (Frederick, Snell & Haywood 1989). Once this radiation passes through the atmosphere it is attenuated further. Terrestrial UV radiation is made up of UVB and UVA radiation, with all UVC radiation completely absorbed in the stratospheric part of the earth's atmosphere (at a height of approximately 40 km) by ozone and molecular oxygen (Webb 1998b). Some UVB radiation is also absorbed by ozone in the stratosphere, but not all (Madronich et al. 1998) while only minimal amounts of UVA are absorbed by ozone (Kerr et al. 2002). The amount of UVB radiation reaching the earth's surface is primarily dependent on ozone, and therefore is variable due to the variable nature of ozone concentrations. This also leads to variation in the lower cut-off wavelengths reaching the earth's surface, due to a combination of ozone and other seasonal effects. Therefore, most photobiological studies restrict themselves to using UVB and UVA wavebands, which are the biologically effective wavelengths that reach the earth's surface.

1.2.2 Biological effects due to UV radiation

The terrestrial solar spectrum is integral to many biological processes on earth. Infrared radiation is important for providing heat energy and warmth to creatures. Visible light is important to photosynthesis in plants and the production of oxygen. This in turn is important to the absorption of UV. However, due to its shorter wavelengths and higher frequencies, UV radiation (in the UVB spectrum) has energies that are capable of breaking bonds between atoms in organic molecules (De Gruijl 2000a) therefore many biological processes can be affected. Sliney (2006) describes this ability to break molecular bonds through the UV absorptive capabilities of molecules and explains how each waveband affects different molecules. Wavelengths shorter than 180 nm are absorbed easily by air – sometimes this UV waveband is called vacuum UV radiation. UVC radiation is actinic in nature, meaning that is causes photochemical reactions. UVC radiation is absorbed by some types of amino acids and proteins, while UVB radiation is less actinic than UVC radiation. However, because it is absorbed less easily, UVB radiation penetrates further into human tissue. The point at which some UVB is absorbed is below the outer layer of the skin, which assists its ability to produce photobiological effects in the body. UVB is considered the most photocarcinogenic of all UV radiation since UVC radiation is not found naturally in the lower atmosphere. UVA radiation is absorbed the least effectively by human tissue, which means it can penetrate further than UVB radiation, but it is also much less photobiologically active. However, the largest penetration depth for UV radiation does not exceed 1mm (Sliney & Chaney 2006). Despite the variation in influence to photobiological effects, UV radiation is considered more hazardous than beneficial, if only due to humans' lack of immediate automatic biological sensitivity to UV radiation. The following sections will discuss both the hazards and benefits of solar terrestrial UV radiation, a topic frequently studied (McCarthy 2004; McKenzie, Liley & Bjorn 2009).

1.2.2.1 Beneficial biological effects to mankind

The sun gives us many things that support human life including light, warmth and energy. Studies of sunlight date back to Sir Isaac Newton in the mid seventeenth century (Mahmoud et al. 2008). The use of sunlight in medicine has been explored since at least 1822 (Holick 2003b; Rajakumar 2007) and the bactericidal action of UV radiation was exploited (Unknown 1916; Rentschler, Nagy & Mouromseff

1940). In the early part of the twentieth century, the discovery that sunlight and specifically UV radiation could help cure people who suffered from rickets, tuberculosis and psoriasis led to the building of solaria so that patients could recover more fully from these diseases (Holick & Jenkins 2003a). Rickets is defined as a disease where bones do not form correctly due to lack of vitamin D_3 and therefore a lack of calcium in the human body. Rajakumar (2003) explains how rickets was noted historically in ancient medical writings and first studied around 1650, but it wasn't until large outbreaks of the disease occurred in the late 19th century and early 20th century in industrialized cities that experiments revealed that lack of sunlight and poor diet were causative factors (Unknown 1922). As a result of extensive studies, an anti-richitic was identified and given a name: Vitamin D (Rajakumar 2007). This was found to be in cod-liver oil. Eventually, through extensive experimenting, the link between sunlight and vitamin D, or more correctly vitamin D_3 production was determined (Atkins 1938; Rajakumar 2007).

It is apparent then that humans obtain vitamin D from their diet or from exposure to UV radiation in the atmosphere. However, over ninety percent of vitamin D_3 in a person's diet is produced through exposure to sunlight (Holick 2003b). Interestingly, vitamin D found in food is not exactly the same as vitamin D_3 endogenously produced from UV irradiance on human skin. UVB radiation, the waveband important to vitamin D_3 production, when incident on the skin, starts a series of chemical reactions. UVB radiation must be absorbed by a molecule called 7-dehydrocholesterol (7DHC), which causes the rearrangement of double bonds (photoisomerisation) to produce pre-vitamin D_3 (Webb 2006). This product in turn undergoes heat isomerisation which eventually produces vitamin D_3 (which takes several hours) and is then circulated through the body (Holick 2004b). Vitamin D_3

itself is not biologically active, therefore it must undergo further reactions in the body to convert it to a hormone that the body can use (De Gruijl 2000a). In other words, vitamin D_3 is really a hormone and not a vitamin (Webb 1993). Despite its ambiguous name, the fact remains that vitamin D_3 is important to humans for the absorption of calcium, which is necessary for good bone health (Holick 2004a) and hence important to the cure for rickets. Holick (2004a) reports that a person who is vitamin D_3 deficient results in only 10-15% calcium being absorbed by the small intestine, while a non-deficient vitamin D_3 person will absorb 30% and providing this continues, can increase to 80% absorption.

In the past few decades, when the detrimental effects due to UV radiation was becoming more and more pronounced compared to the beneficial effects, the message sent to the public from health and government organisations about UV radiation was that it was very harmful and that sunlight exposure should be minimized. This was particularly true for people of European descent living in areas of the world with high ambient UV radiation and whom the campaigns were mostly targeting due to their skin type. As a result from the campaigns of sun awareness, an increase in vitamin D_3 deficiency has been observed. Many studies have looked at other impacts of lack of vitamin D_3. As such, vitamin D_3 deficiency has now been linked with increased risk of cancer (Lucas & Ponsonby 2002) of the prostate, colon and breast (Berwick & Kesler 2005; Garland et al. 2006; Garland et al. 2007), autoimmune diseases including multiple sclerosis, type 1 diabetes and rheumatoid arthritis (Ponsonby, Lucas & van der Mei 2005), cardiovascular disease (Yuen & Jablonski 2010), and obesity (Foss 2009) while sufficient levels of vitamin D_3 has also been linked with protection against infections such as influenza A (Yuen & Jablonski 2010). As a result, there are now an increasing number of studies working out how to balance exposure to UV radiation in order to maintain sufficient vitamin D_3 levels in the body while at the same time not over exposing the body to UV radiation which is associated with many detrimental effects (Reichrath 2006; Samanek et al. 2006; Webb & Engelsen 2006). Of course, it is possible to obtain some vitamin D through diet (such as supplements or consumption of oily fish), but this does not always guarantee sufficient vitamin D_3 levels, due to lack of understanding about the supplements and how they work, and for people who do not have access to or cannot afford to consume oily fish on a regular basis. Instead, it is much simpler (and less expensive) for most people to obtain vitamin D_3 from the sun.

1.2.2.2 Hazardous biological effects to mankind

UV radiation has been linked to numerous detrimental effects since the beginning of the twentieth century, but even now, there is much that is still not known about the hazardous effects UV radiation is linked with. UV radiation is the cause of or has been linked with sunburn (erythema), photoaging, eye damage, immune suppression, DNA damage and mutations and non-melanoma and melanoma skin cancers (Godar 2005).

1.2.2.2.1 Erythema

Historically, at the same time that sunlight was appearing to be useful in helping to treat patients with different maladies, questions were already being raised about the safety of prolonged exposure to direct sunlight (Unknown 1916). By this time period, it was already known that over exposure to sunlight produced a delayed reaction in irritation to the skin, called erythema, although identification that UV radiation was the cause is not specified in that particular paper. Otherwise known as sunburn, erythema is an acute cutaneous inflammatory reaction of the skin due to over-exposure to UV radiation which is characterised by redness, warmth, and oedema (known as swelling) (Honigsmann 2002). Erythema can appear within half an hour to six hours of exposure time (Hawk 1982) and depends on the duration of exposure to UV radiation, skin type of a person, as well as various factors that influence UV radiation itself (Honigsmann 2002). The redness of the skin is due to increased blood content near the skin surface and will reach a maximum redness at 8 -12 hours after exposure, and gradually fade in a few days (ICNIRP 2007) although this depends on the severity of the erythema or "burn". The use of the word "burn" can be somewhat misleading since traditionally burns are characterised by extreme temperatures (very hot or very cold) or chemicals. Instead, the "burn" results from phototoxicity or actinic effects (photochemical reactions) caused by UV radiation (ICNIRP 2007). UVC radiation is two to three times more effective at producing erythema than UVB radiation, and UVB radiation is 1000 times more effective at producing erythema than UVA radiation (Hawk 1982). This indicates that different wavelengths (and therefore different photon energies) have different efficacy at producing erythema. This is true of most photobiological effects (Horneck 1995). The effectiveness of wavelengths in the UV waveband to cause erythema is represented by the erythemal action spectrum (CIE 1987) as shown in Figure 1.1.

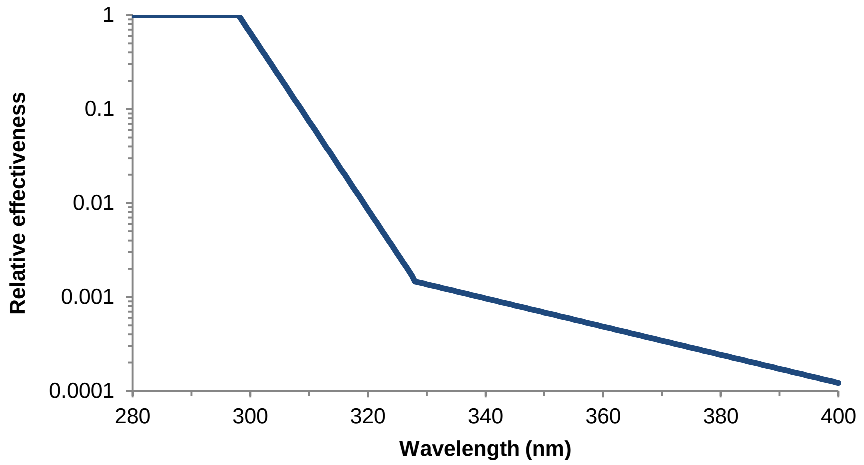

Figure 1.1 - CIE erythemal action spectrum (CIE 1987).

This action spectrum was superseded by clarification of measurement as reported by the CIE (1998) as endorsed by Webb et al., (2011), although to the eye, the relationship would be appear to be the same as Figure 1.1, despite variations between the two that are outlined by Webb et al., (2011). To determine an action spectrum for biological responses it is typical to study the relationship between surface exposure and the resulting response at individual wavelengths (De Gruijl 2000b). This is important since not all absorbed photons of energy cause a response. Instead, only a proportion of all absorbed photons may cause a photobiological response (De Gruijl 2000b). An action spectrum represents this proportion of effective photons per unit wavelength, commonly using a scale of zero to one. This scale can then act as a fractional weighting system, that when applied across the appropriate spectrum of wavelengths will represent only the biologically reactive radiation (Figure 1.2). As can be seen in Figure 1.1, the biological effects can change by the order of magnitude rather than just fractional, and so must be represented logarithmically since this would not be apparent in a standard 0 to 1 scale.

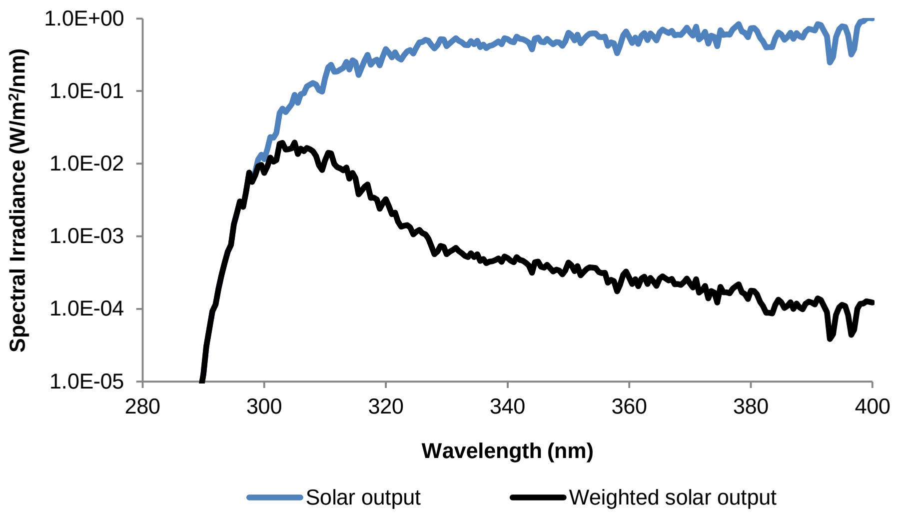

Figure 1.2 – Unweighted and erythemally weighted solar UV spectrum (measured 12.20pm, 6 January, 2009).

The biological characteristics of a person with erythemal UV exposure also dictate how their body will respond, as mentioned previously, due to skin type. People with fair skin require less exposure time to induce erythema, while people who have more pigmented skin will require longer exposure times to induce erythema, or else they may not receive erythema at all. Fitzpatrick (1975) quoted in Diffey (1991) determined a relative grading scale of six sun reactive-skin types (Table 1.1).

Table 1.1 – Fitzpatrick skin type table compiled from Holick & Jensen (2003), ICNIRP (2007) and Diffey (1991).

Skin Type	Sun Sensitivity	Sunburn Susceptibility	Exposure to Burn (SED)	Tanning ability	Characteristic features
I	Very Sensitive	Always burns	< 2	Never tans (no tan)	Fair with red/blonde hair; freckles
II	Moderately Sensitive	High	2-3	Rarely tans (light)	European descent (Scandinavian/Celt)
III	Moderately insensitive	Moderate	3-5	Gradually tans (medium)	Occasionally burns; Mediterranean and Middle East Origins
IV	Insensitive	Low	5-7	Always tans (dark) + exhibits IPD	Seldom burns; East Asian, Indian and Pakistan origins
V	Insensitive	Very Low	7-10	Always tans + exhibits IPD	Rarely burns, natural brown skin; African, South East Asian and some Indian and Pakistan origins
VI	Insensitive	Extremely Low	>10	Always tans darkly + exhibits IPD	Never burn; natural black skin; African and Tamil origins.

1.2.2.2.2 Skin changes – tanning, pigmentation and photoaging

Exposure to UV radiation can cause tanning (skin darkening) through two different methods: immediate pigment darkening (IPD) and delayed tanning (DT) (Diffey 1991). The tanning process really depends on the individual, where fair skinned people (types I and II) will undergo an erythemal response before any pigmentation appears (and therefore will not undergo IPD) whereas less fair skinned people (types III, IV and above) are more likely to undergo IPD (Honigsmann 2002). IPD is mostly dependent on UVA radiation, while both UVB and UVA are capable of causing DT (Mahmoud et al. 2008). Tanning is essentially the production of melanin pigmentation (coloured protein) in the skin (Diffey 1991). Melanin has been called nature's sunscreen because it is supposed to have a dual purpose of filtering UV radiation through physical and chemical means (Jablonski & Chaplin 2003). However, individuals with low numbered skin types who induce tans through UV exposure are not strongly protected from UV radiation, may have small protection factors (Honigsmann 2002) but some argue otherwise, citing the inverse correlation of skin pigmentation with the incidence of sun-induced skin cancers (Brenner & Hearing 2008). In fact, the photoprotection of different skin types has been estimated, where relative protective factors of 1.0, 1.67, 2.50, 3.93 and 9.68 were calculated for skin types I, II, III, IV & V together, and VI respectively (Cripps 1981). Note that types IV & V are grouped together resulting in an average relative protective factor for both skin types, indicating that both skin types may have been considered very similar at the time the research was conducted. While it would appear that there is no detrimental effect due to tanning and changes in pigmentation, further discussion on melanocytes, the cells that produce melanin, will show that they are important to melanoma skin cancer, a potentially lethal disease. In fact, the degree of pigmentation (and therefore skin type and ease of tanning ability) are the most useful predictor of skin cancer (Lin & Fisher 2007). Photoaging is characterised by dryness, deep wrinkles, loss of elasticity, skin sagging and mottled pigmentation (Diffey 1991). It is caused by cumulative exposure to UV radiation and depends on levels of sun exposure and skin pigmentation (Fisher et al. 2002) and is considered due predominantly to UVA radiation, which penetrates further into the skin than UVB radiation.

1.2.2.2.3 Skin cancer

Skin cancer is a growing problem worldwide, where Australia has one of the highest rates of skin cancer in the world (McCarthy 2004). Skin cancer has been identified as being caused by UV radiation since the 1930s (Albert & Ostheimer 2003) and 1940s (Blum 1948). Cancer is one of the main causes of death in the world (Celik, Hayran & Yuce 2010), and compared to other types of cancer (named according to where or how the cancerous cells arise), skin cancer is one of the most common types of cancer (McCarthy 2004). Cancer starts at the level of cells, whereby the cell is damaged or mutated to produce a cancer cell by carcinogenic causes which are either physical, chemical or biological (Celik, Hayran & Yuce 2010). UV radiation has been identified as one of the main carcinogens in the etiology of skin cancer (IARC 1992) although there are many contributing risk factors such as those listed by Alam & Ratner (2001) for squamous cell carcinoma, and this list has a number of factors that are also themselves directly linked with UV exposure. The process of producing a cancer cell is a little more complicated than the outline above and can be better understood through damage to DNA (Leffell & Brash 1996).

Skin is the largest organ of the human body, responsible for absorbing incident irradiance. There are three layers making up skin, the outer layer called the epidermis, the next layer called the dermis, and then the subcutaneous layer. There are many sources that explain the biology of the skin and the following references were used (Unknown 2004, 2010). The outermost layer of skin, the epidermis is only as thick as a piece of paper and therefore only several cells (keratinocytes) deep, which shed continuously. The outermost keratinocytes are dead, while underneath there are squamous cells (living keratinocytes) that are continuously replaced by cells rising up from the basal layer (the lowest part of the epidermis). Keratinocytes at the base of the epidermis are called basal cells, and they divide to make the new keratinocytes to replace the cells that wear off at the skin's outermost surface. Between the epidermis and the dermis there are cells called melanocytes that produce a pigment called melanin. There are two main types of skin cancer: non-melanoma and melanoma, named due to the position of the skin in which they occur.

1.2.2.2.3.1 Non-melanoma

Non-melanoma skin cancer (NMSC) occurs in the epidermis. There are two types of NMSC; basal cell carcinoma (BCC) and squamous cell carcinoma (SCC). NMSC accounts for nearly 90% of all skin cancers diagnosed worldwide (Garner & Rodney 2000). Both types of NMSC arise from the basal layer of the epidermis, however BCC are also thought to arise from cells in hair follicles or sebaceous glands (Elwood 2004). BCC is the most common skin cancer in people with low numbered skin type (Caucasian or European descent) and the detection rate is increasing by 10% per year (Wong, Strange & Lear 2003). BCC is the most common skin cancer where approximately 80% of all NMSC are diagnosed as BCC (Alam & Ratner 2001). They also grow very slowly, so while they are capable of metastasizing (spreading throughout the body) which can be quite destructive in the local area around the cancer (Wong, Strange & Lear 2003), they are mostly removed surgically before metastasis and therefore are rarely lethal (Unknown 2010). SCC occur less commonly than BCC, however, SCC have a higher risk of metastasis (Garner & Rodney 2000; Alam & Ratner 2001) and can be more aggressive once metastasized (Ramos et al. 2004). SCC are generally considered by most researchers the skin cancer that is definitely linked to UV radiation since they occur predominantly on the head and neck (Leffell & Brash 1996; Alam & Ratner 2001), and the next most predominant position is the trunk of the body (Alam & Ratner 2001). Despite occurring in the same layer of the epidermis, the epidemiological evidence that links

BCC with UV radiation is slightly different to the epidemiological evidence that links SCC with UV radiation (English et al. 1997). The review by English et al., found that over numerous studies SCC was strongly linked to total exposure including both occupational exposure (people who work outside) and non-occupational exposure, while BCC was more associated with non-occupational exposure. Total UV dose is also important to occurrence of NMSC, where exposure to high UV doses increases incidence of development of NMSC, where SCC is more affected than BCC (Ramos et al. 2004). UVB radiation is believed to be mainly responsible for NMSC cutaneous damage (Dessinioti et al. 2010) and specifically for total cumulative exposure in SCC (Vitasa et al. 1990). BCC appears to be more closely linked to people with the type of skin that burns easily or tans poorly but with intermittent UV exposures (Vitasa et al. 1990; Kricker et al. 1995; Green et al. 1996). However, despite the differences between the role of UV radiation in NMSC skin cancer induction, it is agreed by most that UV radiation plays a very important role in all types of skin cancer (Kricker et al. 1995; Green et al. 1996; Leffell & Brash 1996; English et al. 1997; Armstrong 2004).

1.2.2.2.3.2 Malignant melanoma

Malignant melanoma occurs in the transitional layer between the epidermis and the dermis (sometimes called the basement membrane) (Unknown 2010) from cells called melanocytes (Gray-Schopfer, Wellbrock & Marais 2007). Out of all the skin cancers, the relationship between malignant melanoma and UV radiation is the most controversial, with conflicting data that both implies and negates the causative power of UV radiation in producing malignant melanoma (Maddodi & Setaluri 2008). Some studies and reviews find no link between UV exposure and incidence of malignant melanoma development (Cascinelli & Marchesini 1989). There is one report that simply claims no relationship (Christophers 1998) rather suggesting it is temperature of the skin that correlates with malignant melanoma, but supplies no data to support the hypothesis. A majority of studies do find correlation between UV exposure and malignant melanoma development (Setlow et al. 1993; Walter, King & Marrett 1999; Armstrong 2004; Berwick et al. 2005). Analysis of the many studies carried out have shown that the strongest correlation of UV exposure as a risk factor for developing malignant melanoma occurs with intermittent sun exposure and sunburn history (Elwood & Jopson 1997; English et al. 1997; Gandini et al. 2005). These same risk factors are similar for BCC, but not for SCC as mentioned earlier. Even the specific UV wavelengths that contribute to induction of malignant melanoma is a controversial topic, where due to the apparent link between sunburn and melanoma, it was thought that UVB radiation was primarily responsible for melanoma induction (Setlow 1974) which showed DNA damage was more effective at wavelengths below 305 nm. Further studies soon started to show that UVA was also capable of causing melanoma (Setlow et al. 1993; de Laat, van der Leun & De Gruijl 1997; Wang et al. 2001; Mitchell 2006; Mouret et al. 2006) although others have recently shown that UVA does not initiate melanoma (De Fabo et al. 2004; Mitchell et al. 2010). There are many variables relevant to the induction of malignant melanoma, including childhood UV exposure, although Pfahlberg, Kolmel & Gefeller (2001) suggests total duration of UV exposure may be less important than total sunburn suffered throughout a person’s lifetime, which has been confirmed by follow up studies (Maddodi & Setaluri 2008). In an unusual study, Hallberg & Johansson (2004) claim that electromagnetic fields due to FM broadcasting of body resonant frequencies plays a role in mortality due to malignant melanoma, through impairment of cell repair and autoimmune system mechanisms. Despite the controversies and contradictions surrounding development and results of malignant melanoma, many studies agree with the reasoning of Brenner and Hearing (2008), which shows the action spectrum for UV induced tanning and the erythemal action spectrum are almost identical, and only differ in the type of UV that is more efficient at each biological response. It was previously stated that the degree of pigmentation (and therefore skin type and ease of tanning ability) are the most useful predictor of skin cancer (Lin & Fisher 2007), therefore, it stands to reason that induction of tans and erythema are also used as predictors of skin cancer in an individual and therefore is a result of UV radiation exposure.

1.2.2.2.4 Eye effects

UV radiation penetrates the eye more deeply than any other structure in the human body (Zigman 1993). Wavelengths of 300 nm or shorter are absorbed by the cornea (the transparent membrane at the front of the eye), where the absorbed energy contributes to photokeratitis, otherwise known as welder's flash (Ambach & Blumthaler 1993) or snow blindness (Diffey 1991). Of the two names, it was called snow blindness because it is the UV radiation that is reflected from the ground or lower surfaces (for example snow) that causes the over-exposure of the eye to UV radiation. Reflected UV radiation in eye exposure studies can be underestimated (Sliney 1994). Snow blindness requires a long exposure time, unlike welder's flash, which is short term exposure to much lower wavelengths in the UVC waveband (and therefore more damaging and more intense) (Ambach & Blumthaler 1993). The eye, unlike the skin, does not adapt to repeated UV exposures (ICNIRP 2007), hence further UV exposure can cause further problems, such as the formation of cataracts, which artificial UV exposure is known to contribute to although there is limited evidence linking chronic solar exposure to all types of cataracts (WHO 1994). A cataract is a clouding of the part of the eye causing opacity when there should be transparency and as a result of the cataract, limiting vision (Gallagher & Lee 2006). Specifically, UV is linked to the development of cortical cataracts which are cataracts that develop on the outer part of the cornea as opposed to the centre or inner part of the cornea (West et al. 2005) or cataracts of the lens. A much rarer condition, ocular melanoma, has been linked with UV exposure, and it is more likely to occur in subjects with light skin and hair, and blue or grey eyes (Gallagher & Lee 2006).

1.2.2.2.5 Immune suppression

The link between skin cancer and UV exposure was integral to the developing understanding between UV exposure and its immune suppression effects, with studies starting in the 1960s. Specifically, UVB and UVC radiation was found to be responsible for changes to immune responses, but even just UVB radiation in sunlight is capable of initiating immune suppression (Noonan & De Fabo 1993). Immune suppression due to UV radiation is important because it seems to be linked specifically to other UV related diseases such as skin cancers. In other words, immune suppression due to UV could be a protective mechanism, to protect from autoimmune diseases from sun damage. However, when very high doses of UV are involved, it potentially allows the growth of skin cancers by suppressing tumour-specific immunity functions (De Fabo & Noonan 1983). Later studies have suggested UVA radiation may in fact be also responsible for immunosuppression (Baron et al. 2003) a conclusion resulting from the sunscreens used in the seventies and eighties, which protected from UVB radiation but effectively transmitted through filtered UVA radiation. Without broad spectrum sunscreens, people were exposing themselves to higher levels of UVA radiation while protecting themselves from

UVB, where the natural mechanism of erythema was essentially de-activated, causing a person to seek shelter when erythema was eventually detected.

1.2.2.2.6 DNA damage, mutation and other effects

UV radiation is able to damage DNA, which in turn can cause mutations that may lead to development of tumours (Clydesdale, Dandie & Muller 2001). This is because organic molecules tend to absorb UV radiation easily, and more specifically, organic molecules with conjugated bonds (De Gruijl 2000a). The specific UV wavelengths absorbed depends on the molecule itself, with DNA absorbing strongly at 260 nm, but wavelengths above 290 nm can still inflict damage on DNA that is not protected by overlying or nearby cells (De Gruijl 2000a). Leffell & Brash (1996) describes the process. The mutations caused by UV damaged DNA resulting in NMSC are thought to occur through alterations to the p53 gene which normally functions as a suppressor of tumour development. The gene must repair itself, but with the absorption of UV, may not repair itself correctly and thus cause a mutation. Most mutated cells are not a problem due to apoptosis (programmed cell death) but it can be if the mutation itself suppresses apoptosis. As described by Leffell & Brash (1996) UV radiation “burns” healthy cells, which mostly undergo apoptosis and are replaced by new cells that are made in reference to nearby cells. If one of those nearby cells should be a p53 mutated cell, then the new replacement cells may be made using the mutated cell as a base, thus producing more mutated cells. It is this proliferation of mutated cell growth that leads to actinic keratosis (Alam & Ratner 2001) or a tumour. The reason that NMSC such as SCC are identified as being caused by UV radiation is that mutations caused by UV radiation are specific, and are unable to be produced with any other sort of carcinogen (Leffell & Brash 1996).

There is much information on the specifics of gene mutation and its products, for example (Mitchell & Karentz 1993; Mouret et al. 2006).

Other effects that UV radiation may be linked with include the interactive effects of UV radiation where threshold dosages may be important for good health. Most particularly is the production of vitamin D_3. As discussed earlier, lack of vitamin D_3 is associated with other forms of cancer, where by balancing moderate doses of UV exposure may assist general health. In other words, too much UV exposure can cause NMSC while not enough UV exposure may inadvertently contribute to other types of cancer (such as breast or colon cancer). Current literature is reinforcing this body of knowledge (Tuohimaa et al. 2007; Grant 2008), while lack of vitamin D_3 is also postulated to be linked with obesity (Foss 2009) and sufficient vitamin D_3 levels may contribute to lowering of hypertension (Godar 2005).

1.2.2.3 Ecological biological effects

UV radiation is important to other players in the biosphere, including microbes, plants and animals (Paul & Gwynn-Jones 2003). Some animals detect UVA radiation as a part of their visual systems, where food selection and mating ability may be dependent on UV reflection (Paul & Gwynn-Jones 2003). In lieu of increased amounts of UV radiation in the atmosphere, many studies have been carried out on effects to terrestrial and aquatic ecosystems. (Xiong & Day 2001; Paul & Gwynn-Jones 2003; Caldwell et al. 2007; Hader et al. 2007). Depth penetration of UV into water bodies vary, but changes in some UV radiation penetration can affect many aquatic species, including eggs and larvae of all species, such as plankton (picoplankton, phytoplankton and zooplankton), macroalgae and other aquatic plants and sea urchins (Hader et al. 2007). There are a variety of other factors that also contribute to changes in biological effects for all of these biological entities, and for other aquatic life forms such as coral, sea anemones, amphibians and fish are thought to be indirectly affected by UV radiation due to changes in other climatic factors (Hader et al. 2007). Numerous studies have been carried out using plants subjected to increased levels of ambient UV exposure. Biological effects include plant growth inhibition, changes in acclimation responses, changes in plant chemistry and interactions between plants and synergistic and consumer organisms (such as herbivory, fungi, microbial communities) (Caldwell et al. 2007). The former topics are direct effects of changes in UV radiation while the latter are indirect effects. As with most ecological systems, there are many factors that work together to produce optimum conditions for any biological entity, and it is obvious that UV radiation plays an important role in ecological systems on earth, but defining exactly how UV functions for every different type of organism is difficult. Many studies have been carried out in Antarctica where maximal changes in UV radiation are investigated for the effects on biological organisms, both on land (Xiong & Day 2001) and in the ocean (Davidson & Belbin 2002).

1.2.3 Variations in UV radiation levels at the earth's surface

From the previous discussions, it is apparent that monitoring UV radiation at the earth's surface is important in understanding the etiology of the many biological effects UV radiation is believed to contribute to. There are however, many factors that contribute to variations in UV radiation reaching the earth's surface, and if we are to truly understand how UV radiation causes biological effects, we need to understand how the UV radiation reaches the surface and why it may differ in intensity from hour to hour, day to day, week to week, month to month and year to year. In addition, this information on variability in the UV transmission to the earth's surface can then also contribute to building operational applications such as estimating surface UV radiation, with examples of forecasting of the UV Index, estimating surface UV irradiance from space and estimation of UV penetration under water (Kerr 2003). The majority of research on changes in UV radiation levels and consequential biological effects began when depletion of ozone was discovered over Antarctica, potentially resulting in increased UV radiation levels at the earth's surface (Sommaruga 2009). Kerr (2003) describes the main influencing factors affecting UV radiation reaching the earth's surface as geometrical and geophysical variables. Geometrical variables include changes in the earth-to-sun distance and the position of the sun in the sky relative to a geographical location on the earth's surface. Geophysical variables include physical effects on the passage of UV radiation through the earth's atmosphere. The geometrical factors will be discussed here first before addressing the geophysical factors. Out of the many variables that influence UV radiation, temperature however is not one of them, which is in contrast to the effect of UV radiation on ozone and oxygen in the stratosphere, in which UV radiation controls the thermal profile of the stratosphere (Lean 1997).

1.2.3.1 Extraterrestrial UV

Knowledge of extraterrestrial UV irradiance is important due to its influence over geophysical processes, particularly stratospheric ozone (Kerr et al. 2002). Additionally, uncertainty in measurements of extraterrestrial UV radiation leads to uncertainty in measurements of UV radiation at the earth's surface since the two measurements are compared to each other via a radiative transfer equation that governs attenuation of radiation passing through the atmosphere (Bais et al. 2007). Variation in solar activity due to the solar cycle only minimally affects the UV radiation reaching the earth's surface, but it is important to the UVC wavelengths relevant to stratospheric ozone production (Madronich 1993; Bais et al. 2007) and produces up to 3% variation in ozone levels (McKenzie et al. 2003). The time period under review can be also important where Gerard (1990) reports variations in ultraviolet radiation due to the 27 day solar rotation period and 11 year solar cycle, and resulting in changes in the ozone column from 2% to 3.5% over a five year period. As a result, an indirect effect on UV radiation at the earth's surface is possible. For example, a weakening of solar activity might cause less UVC radiation to produce less ozone, and therefore allow more UVB radiation through to the earth's surface (Bais et al. 2007). The extraterrestrial spectrum varies by 10% or less per year, but UV radiation at the earth's surface varies much more due to the geophysical factors (Gies, Roy & Udelhofen 2004). Despite the large variations, only a small proportion of radiation reaching the earth's surface is actually UV radiation, where UVB contributes 0.04% and UVA contributes 6.5% to the entire solar spectrum at the earth's surface while extraterrestrial quantities are 1.4% and 6.8% respectively (Gies, Roy & Udelhofen 2004). However, the further back into history one delves, the numbers change, for example the numbers being reported in the 1990s were 1.5% extra terrestrial UVB radiation that became 0.5% UVB radiation at the earth's surface (Blumthaler 1993). McKenzie et al(2003) suggests there may be other possible types of climatic impacts due to solar variability including changes in cloud cover, but evidence to confirm this may be a long time coming since variability observed in the sun appear to occur over much longer time scales. Regardless, the importance of extraterrestrial UV radiation is its intricate balance with production of ozone and therefore indirectly affecting the UV radiation that does eventually reach the earth's surface.

1.2.3.2 Geographical location

UV radiation reaching the earth's surface varies according to geographical location (Seckmeyer, Albold & Mayer 1997; Kimlin 2008; Lee-Taylor et al. 2010) as indicated by variation in average doses to UV exposure. The variations in UV radiation due to geographical location are not just a result of geography (latitude and longitude), but are due to a combination of geometrical and geophysical factors including the observer's altitude, seasonal variations and the position of the sun in the sky.

1.2.3.2.1 Altitude

UV radiation reaching the earth's surface at different altitudes is affected by the total air column that it must travel through in the atmosphere (Piazena 1996) which means that the higher the altitude, the lower the attenuation which will result in higher UV radiation intensity measurements (Parisi, Sabburg & Kimlin 2004a). The attenuating effects of the atmosphere cause variation even at similar altitudes, so the effect of altitude has been explored at various altitudes, around the world including the Chilean Andes (Piazena 1996), the European Alps (Schmucki & Philipona 2002) and in Germany and Bolivia (Pfeifer, Koepke & Reuder 2006).

1.2.3.2.2 Latitude and longitude

The shape of earth itself governs the intensity of UV radiation reaching the earth's surface at different positional locations. The tilt of the earth's axis orients the northern and southern hemisphere either closer or further away from the sun, and combined with its annual orbit creates differences in UV radiation intensity (Parisi & Kimlin 1997) which of course contributes to seasonal changes. UV radiation intensity decreases the higher the latitude (Godar 2005) due to the increasing path length it has to travel in the atmosphere, but changes in other geophysical parameters such as ozone then contribute to UV radiation levels at specific latitudes.

Longitudinal variations in UV radiation tend to be minimal and any variations observed indicate it is more likely to be due to climate of the area under consideration (Godar 2005).

1.2.3.2.3 Seasonal variation

Despite the inability of the solar activity to significantly influence UV radiation reaching the earth's surface, the relative position between the earth and the sun does influence the intensity of UV radiation reaching the earth's surface. The distance between the earth and the sun varies by about 3.4% (Madronich 1993) which leads to seasonal UV variation by about 7% due to the inverse square law (Kerr 2003; Seidlitz & Krins 2006) which produces the seasonal difference in UV radiation levels per season for each hemisphere. Due to this variation in earth-sun distance, the tilt of the earth's axis and a number of other factors including ozone content and pollution, the southern hemisphere receives higher UV irradiance than the northern hemisphere (Madronich 1993; Herman 2010). Essentially, both latitude and seasonal variation in UV radiation are mainly due to the position of the sun in the sky and duration of sunlight over the day time (Frederick 1993), which means that solar elevation is one of the dominating variables that controls UV radiation reaching earth's surface.

1.2.3.3 Solar zenith angle and solar azimuth angle

The spectrum and intensity of UV radiation varies with the position of the sun in the sky (relative to a position on earth), otherwise known as solar elevation (Diffey 2002a). The solar elevation is described in terms of solar zenith angle (SZA) and the solar azimuth angle (SAA) and is the most significant factor influencing UV irradiance levels (Zerefos 1997). The SZA is essentially the height of the sun in the sky but is more correctly defined as the angle between the zenith point of the sky (the highest point in the sky) and the sun, where the smaller the SZA the higher the sun is in the sky and the larger the SZA, the lower the sun is in the sky. The SAA is the position of the sun in the sky with respect to geographical north and is normally measured using north as 0°, and one full revolution clockwise around the compass points from north is 360°, however there can be variation in representing solar azimuth depending on the location on the earth where the measurements are made. SZA and SAA at any location vary with time of day, year and geographical location (Madronich 1993; Diffey 2002b), which means they are constantly changing as the earth rotates about its axis and orbits the sun. These descriptors can be expressed diagrammatically (Coakley 2003). As a result, the total path length of UV radiation travelling through the atmosphere is also changing, where the shorter the path length to the earth's surface, the less interaction with the geophysical factors of the atmosphere, while the longer the path length, the more interaction with geophysical factors and therefore greater attenuation of UV radiation. For these reasons solar UV irradiance on a horizontal surface is weighted according to the cosine of SZA, and as a result the smaller the SZA, the less absorption or scattering is observed. This is supported by maximum UV irradiance intensity occurring around solar noon, given factors such as clouds are not present, resulting in 50 to 60% of UV exposure occurring in the hours bracketing solar noon (approximately 4 to 5 hours) (Diffey 2002b) for any location regardless of the SZA or SAA in an area (except for the highest latitudes and polar regions where the sun may not come above the horizon in winter months).

1.2.3.4 Ozone

Earth's atmosphere is divided into four layers, the troposphere (0-15 km), the stratosphere (15-50 km), the mesosphere (50-80 km) and the thermosphere (80-200 km) (Linacre & Geerts 1997c). The majority of the content of the atmosphere (around 90%) is located in the troposphere, while most of the remainder is found in the stratosphere. Energy at different wavelengths emitted from the sun may be absorbed in the atmosphere, and depending on the wavelength of the energy, can be absorbed in different parts of the atmosphere, or else not absorbed at all. UVC radiation causes ozone production (Lean 1997; Haigh 2003) as a result of being absorbed in the stratosphere. UVC radiation is absorbed by molecular oxygen (O_2), which splits into atomic oxygen (O). Atomic and molecular oxygen, due to their electron configurations, combine to produce triatomic oxygen (O_3) otherwise known as ozone. As a result of the breaking of molecular bonds, this process also produces heat that contributes to thermal profile of the stratosphere (Lean 1997; Haigh 2003).

Compared to total atmospheric content, ozone exists only in trace amounts (Dessler 2000a). Nevertheless, the presence of ozone in this part of the atmosphere is vital to the earth's biosphere, because ozone filters out the biologically hazardous wavelengths within the UVC and UVB radiation wavebands. This filtering can be observed through the resulting UV spectral irradiance intensity which drops by six orders of magnitude over a 20 to 30 nm interval in the UVB waveband (Seidlitz & Krins 2006). Specifically, wavelengths up to and around 290 nm will be absorbed by ozone (Rowland 2006), which is split into atomic and molecular oxygen, only to be cycled back into the ozone and oxygen conversion reactions. There are also many reactions that serve to destroy ozone in the atmosphere (Rowland 2006) in larger capacities compared to ozone production. These reactions occur when compounds are introduced to the stratosphere that interacts with ozone.

Walker (2007) explains the story behind the discovery of the ozone hole, a man-made phenomenon of ozone depletion located predominantly over Antarctica in which the ozone in the atmosphere is affected by the presence of chlorine ions introduced through normally stable compounds known collectively as CFCs (chlorofluorocarbons), used specifically in refrigeration and aerosol cans. The story can in fact be traced back to 1881, when Hartley (1881) as referenced from Walker (2007) worked out that UV absorption occurred due to ozone, and that placement of the ozone in the atmosphere was particularly important to the UV radiation reaching the earth's surface. In the 20th century, (James) Lovelock decided to measure the quantities of CFCs in the atmosphere near his home in Britain, believing them to be responsible for the haze (along with other forms of pollution) he observed near his home. His measurements suggested this was true. He then extended the study, measuring CFC quantities in the Atlantic ocean (Lovelock, Maggs & Wade 1973) and in the atmosphere over the ocean (Lovelock 1974) which showed quantities that were surprising despite the distance from populated areas. The information published was then taken up by researchers Molina and Rowland who wanted to know what happened to CFCs in the atmosphere. It was realized that CFCs could be broken apart in the stratosphere via incoming UV radiation, much like ozone and oxygen. Unfortunately, the free chlorine atoms from the CFC molecules were also exceptionally good at removing the extra oxygen atom from ozone molecules, assisted in reverting the ozone back to (diatomic) oxygen and in this process, freeing itself to repeat the ozone destruction reactions again and again (Rowland 2006). Molina & Rowlands' calculations suggested significant ozone loss (Molina & Rowland 1974) and they argued that the production and use of CFCs should be banned. As with many conclusions that suggest imminent disaster, there was resistance to this recommendation, for there were no actual recorded ozone depletions to back this up. An enquiry was set up to review Molina and Rowland's work, which eventually agreed with the findings. However, it was not until 1985 that the situation changed, when the British Antarctic Survey team demonstrated that ozone levels measured during spring in the late 1970s, had fallen below the levels observed during the period 1957 to 1973 (Farman, Gardiner & Shanklin 1985). Farman, Gardiner & Shanklin postulated that chlorine reaching the stratosphere was causing the destruction of ozone, a conclusion later supported by a confirmation that CFCs carried chlorine into the stratosphere.

Chlorine isn't the only culprit in destroying ozone, with previous work having already shown that nitrogen oxides were also capable of ozone destruction. In fact, with development in the 1970s of supersonic passenger aeroplanes flying in the stratosphere, a concern arose that nitrous oxides in the exhaust from these planes (van der Leun 2004) could also cause ozone destruction (Crutzen & Arnold 1986). In the end, it wasn't the supersonic planes' exhaust that caused significant problems. Other chemical elements make it to the stratosphere to eventually exist as free radicals, and have been shown to be just as damaging (if not more) to ozone as chlorine, such as bromine (Wennberg 1999) which is up to 60 times more effective than chlorine at converting ozone to oxygen (WMO 2006).

The ozone "hole" was not really noticed until after Farman et al., (1985) had published their work, which was strange since satellite monitoring of ozone had been carried out all throughout the same time period. The satellite monitoring system had been picking up the data, but due to the program design, had been discarding the data as it was considered to be outside acceptable parameters (Benestad 2002). Once the mistake was rectified, there was a clearly noticeable depletion of ozone showing up over the Antarctic region in spring, supporting the previous studies. There are certain climatic factors in Antarctica that contribute to the highly visible "hole" in satellite images including polar stratospheric clouds which act as a catalyst for many reactions in the atmosphere. There is also the polar vortex, a climatic condition that is able to separate the polar air mass from lower latitude air movement through strong pressure gradients (Dessler 2000b). The ozone hole is in reality not an isolated phenomenon, and depletion of ozone levels worldwide have since been observed, as has a "hole" forming over the Arctic (Muller et al. 1997), despite the differing climatic conditions to Antarctica (Walker 2007).

As a result of stratospheric ozone depletion, a great deal of research has been carried out to predict increases in UV radiation reaching the earth's surface (Paul & Gwynn-Jones 2003). The predicted changes in biologically effective UV radiation reaching earth's surface is 0.2 to 2% increase for every 1% decrease in ozone (Madronich et al. 1998; McKenzie et al. 2003) depending on the UV wavelengths of interest, but there is evidence of increased UV irradiance due to low local ozone columns in specific areas studied where Alessandro, Siani & Casale (2002) is just one example. The growing concern resulting from ozone depletion (apart from climatic changes and potential consequences with global warming) is the changes in health effects on humans and the biosphere. There are many studies that have sought to determine the general effect such as Madronich et al., (1998) and McKenzie et al., (2003), and most of the papers discussed in the section pertaining to biological effects have arisen from the potential consequences of ozone depletion. There are many more including (Madronich & de Gruijl 1994; Armstrong 1997; Micheletti, Piacentini & Madronich 2003; Schmalwieser et al. 2009) and (Slaper & De Gruijl 2004) as just an example of overall effects while others have attempted to measure effect of ozone on skin cancer incidence (Kane 1998; Abarca & Casiccia 2002) although there is not necessarily positive correlations for some types of cancer (see Section 1.2.2.2.3). Fortunately, not too long after the initial discovery of the 'ozone hole', an international agreement was produced in 1987 called the Montreal Protocol to embark on reducing the use of ozone depleting substances as much as possible (WMO 2006). At the time of the most recent assessment of the Montreal Protocol (WMO 2006) it appears that the protocol is working with measurable reductions of ozone depleting substances in the stratosphere, while the depletion of ozone itself has not worsened. This is despite the fact that there are many contributing factors to variations in ozone concentrations in the stratosphere (Weatherhead & Andersen 2006). There is also the added uncertainty as to how climate change may affect ozone, with the potential to affect the warming that ozone provides to the stratosphere (through the initial production via UVC radiation and molecular oxygen). Cooling of the stratosphere due to added greenhouse gases trapped in the troposphere could cause increased ozone depletion, but warming in the polar regions may help to decrease ozone loss (through less severe conditions in the polar vortex) which will help circulate ozone across the global atmosphere (Schiermeier 2009). There are many other interactions involved in climate change that relate to solar UV through a variety of factors (Matthews & McKenzie 2006) but do not need to be considered here. The interaction between change in ozone concentration and enhanced greenhouse effect causes higher uncertainties in the overall recovery of the ozone layer, and therefore adds another layer of variability that has to be considered. However that is larger than the scope of this research. One of the more investigated variations is cloud cover, which will be discussed next.

1.2.3.5 Cloud

As UV radiation passes through the atmosphere, it encounters the majority of attenuating media in the troposphere. Apart from the gases that make up the atmosphere, clouds cause the most variation through attenuation to solar radiation and in particular to UV radiation. Attenuation is dependent on properties of the cloud, including cloud cover, optical thickness, position of the cloud relative to the sun, cloud type and cloud layers (Calbo, Pages & Gonzalez 2005).

A cloud is defined to be a group of miniscule suspended particles of water or ice in sufficient concentrations as to be visible in the atmosphere (Rangno 2003). The droplets or ice crystals making up clouds are so small that air motion will prevent precipitation, with droplet diameters of approximately 10 micrometers (Linacre & Geerts 1997b). Cloud droplets have only a millionth of the mass compared to raindrops, (Linacre & Geerts 1997b). Due to the droplets composition (water), clouds appear white during a relatively clear day due to Mie scattering (see Section 1.2.3.6). With different concentrations, position and layout in the sky, clouds can reduce all types of solar radiation reaching the earth's surface significantly, as referred to by Calbo et al., (2005). For the most part, clouds tend to reduce UV radiation reaching the earth's surface (Lubin & Frederick 1991), sometimes by up to 99% (Estupinan et al. 1996).

Over the last decade (or two) a change in understanding cloud attenuation of UV radiation has been evolving. Originally cloud attenuation of UV radiation was thought to be independent of wavelength, but some studies then found that cloud attenuated UV was spectrally dependent (Seckmeyer, Erb & Albold 1996; Kylling, Albold & Seckmeyer 1997; Sabburg & Parisi 2006). Despite these findings, this latter conclusion is not universally supported due to confounding factors such as SZA and ultimately a need for further research (Lopez, Palancar & Toselli 2009). The reasoning for the further research becomes more apparent using the following reasoning; UV radiation itself is less affected by cloud (in terms of reduction) than total solar radiation, and similarly, erythemal UV radiation (or UVB radiation or radiation weighted with strong sensitivity in the UVB range) is less attenuated than total UV radiation (Calbo, Pages & Gonzalez 2005). Part of the explanation for this lies in a scattering process that causes higher scattering with shorter wavelengths (i.e., Rayleigh scattering, see Section 1.2.3.6).

In addition to UV radiation reduction, clouds are also able to *enhance* UV radiation due to their location in the sky with respect to the sun (i.e., not obscured by cloud), due to a "lensing effect" by the clouds, which can significantly increase shorter UV wavelength measurement in short time periods, through the transmission of UV radiation through the edges of clouds (Weihs et al. 2000; Sabburg, Parisi & Kimlin 2003). Both the reduction and enhancement of UV radiation by clouds is a result of the ability of UV radiation to be scattered (via reflection and refraction) and even absorbed by clouds.

1.2.3.6 Scattering and absorption

Two of the main components that contribute to scattering and absorption in the atmosphere have already been discussed. Ozone is a significant absorber of short UV radiation in the stratosphere while nitrogen dioxide and sulphur dioxide also absorb UVB radiation (Kerr 2003). All other atmospheric gases, if they are not absorbing UV radiation, are effective scatterers of UV radiation. Clouds are effective scatterers (and absorbers) of UV radiation (Section 1.2.3.5). There are also larger molecules than atmospheric gases. Aerosols are very small solid or liquid particulate matter suspended in the atmosphere, and include examples such as soot, haze, dust and even sea-salt (Parisi, Sabburg & Kimlin 2004a). The scattering processes of atmospheric gases and aerosols contribute to two different types of radiation scattering. Scattering is dependent on the wavelength of the radiation relative to the size of the particles causing scattering. Scattering caused by atmospheric gases (and maybe the smallest of aerosols) which are small compared to the wavelength of solar radiation, such as UV and visible radiation, is called Rayleigh scattering (Linacre & Geerts 1997a). Due to the relative size difference, scattering is inversely proportional to the fourth power of the magnitude of the wavelength (Parisi, Sabburg & Kimlin 2004a) which means that the shorter the wavelength, the greater the scattering. As a result, UVB radiation scatters more than UVA radiation. We can see the result of Rayleigh scattering through the colour of the sky during the day, where the sky appears blue because it constitutes the shortest wavelengths of visible radiation.

Aerosols can range in size, and therefore many particles in the atmosphere, particularly aerosols, actually approach the same relative size as the wavelengths of solar radiation. These much larger particles or droplets cause Mie scattering, which is not proportional to wavelength size, and therefore scatters all radiation relatively equally (Linacre & Geerts 1997a). This can often be observed when the sky takes on a hazy white appearance (hence haze is an aerosol) however, this also helps to explain the whiteness of clouds in the sky, as the tiny water droplets constituting a cloud are the same size as most aerosols. Hence Mie scattering is responsible for the white appearance of clouds (on a sunny day) (Linacre & Geerts 1997a). Because aerosols are not limited to a particular sized group, and can be any shape with any type of interaction possible with UV radiation, the ability to account for the effects of aerosols on UV radiation is very complex (Barnard & Wenny 2010) although some studies reported by Barnard & Wenny indicate there have been decreases in UV radiation reaching the earth's surface with increased aerosols over time. The main result of aerosols in the atmosphere appears to be the increase in scattered UV radiation, referred to as diffuse radiation.

1.2.3.6.1 Diffuse radiation

There are two major components to solar radiation in the atmosphere. Direct radiation that has travelled the shortest path through the atmosphere and has not interacted strongly with the atmospheric constituents, and is highest in measurements under sky conditions when the sun is not obscured. Radiation that has undergone interaction within the atmosphere, through scattering, eventually reaches the earth's surface but not necessarily from the direction of the sun. Radiation that reaches the earth's surface from any or all directions is called diffuse radiation. Whilst the direction of the radiation has changed, and the path it travelled may be longer to get to the earth's surface, the radiation itself undergoes elastic collisions, therefore it retains its energy and does not affect either the frequency or the wavelength overall (Parisi, Sabburg & Kimlin 2004b). This is true for both Rayleigh and Mie scattering. The diffuse radiation component in total UV radiation measurement is significant, and despite the presence of shade, can contribute to UV exposure levels that are capable of causing significant erythemal damage. For many studies the proportion of diffuse to direct UV radiation is very important, especially when clouds are present, which can be similar to the effect of shade, where people can be unaware that erythemal doses can be easily achieved even on a cloudy day. This is due to the Rayleigh effect, where UVB radiation scatters more effectively than UVA radiation and therefore contributes to the erythemal UV radiation (Parisi, Sabburg & Kimlin 2004b). Even without cloud, changing SZA and SAA throughout the day causes variation between the proportion of direct to diffuse UV radiation throughout the day, and the proportion of diffuse UVB to diffuse UVA radiation. Diffuse UV measurements can be difficult to predict, particularly due to the variable nature of clouds on which most studies are based, and may become more significant in the future should increased cloud cover occur (Grant & Gao 2003; Turnbull, Parisi & Downs 2006).

1.2.3.7 Albedo

All objects and surfaces reflect visible radiation to a degree which is how we can physically "see" an object, and in the same respect, all solar radiation is reflected from surfaces. In the previous section discussing diffuse UV radiation, scatterers are one of the most significant contributors to diffuse radiation, and one of the main causes of scattering is reflection. UV radiation reflects from clouds, particles and so forth as it traverses the atmosphere. When UV radiation reaches the earth's surface, it may or may not be absorbed by the medium it comes into contact with and if it isn't, or only partially absorbed, then reflection to different degrees will occur. This is a basic optical principle, in which not all radiation is perfectly absorbed, or even perfectly reflected, but constitute some combination of the two (Lenoble 1993b). The degree to which a surface absorbs or reflects depends on the medium. For visible radiation, this can have a lot to do with the colour of a surface, whereas reflection of UV radiation depends more on the other factors making up a surface; the smoothness of the surface, the density, the type of matter (solid/liquid) and its refractive index (if it is not opaque).

The contribution of UV radiation reflected from surfaces to total UV radiation is determined by using a unitless quantity called albedo, which is essentially the ratio of upwelling UV radiation (from a horizontal surface) to downwelling UV radiation (Blumthaler & Ambach 1988). Albedo was classically understood to be a broadband measurement, comparing the integral of the reflected UV radiation to the integral of the incident UV radiation of the radiation spectrum in question, and has been used in this fashion since the beginning of the 20th century (Angstrom 1925). Despite the implied broadband measurements from the definition of albedo, sometimes it is used in a narrowband sense, either to distinguish certain parts of the solar spectrum, or to differentiate between the UV, solar or infrared spectra (Brandt et al. 2005). Some studies looked at albedo in a spectral sense, such as Feister & Grewe (1995) recording measurements at every 10 nm step. However, for simplicity the same study may describe overall reflective quality converted to broadband measurements or averaged over the measured wavelengths, while others simply represent the data graphically, presenting an albedo proportional to measured wavelength (Coulson & Reynolds 1971).

The problem with the use of albedo is the lack of consistent measurements made by different studies. For instance, some studies refer to albedo as the ratio of total incoming radiation (of any part of the solar spectrum) reaching the top of the atmosphere, and total reflected radiation from the earth at the top of the atmosphere or wherever the satellite or plane is located. One example is the use of the Total Ozone Mapping Spectrometer (TOMS) which was located on the Nimbus 7 satellite (Eck et al. 1987; Eck, Bhartia & Kerr 1995; Kuang & Yung 2000). A variety of instruments are used in albedo measurements, either broadband or spectral. In cases of albedo measurements in the Alps, which look at surrounding areas from instruments set at high altitudes, a variety of methods range from estimation from CCD images and radiation transfer models to calculate albedo (Weihs et al. 2002a) to collecting snow samples to compute radiation reflection due to crystal size (Weihs et al. 2002b) of which the resulting different values were then analysed (Weihs et al. 2002a; Weihs et al. 2002b). Studies that estimate hazards due to UV exposure in similar mountainous terrain need to include some measure of albedo, particularly if snow is present, for example, Grifoni et al., (2006) records 80% albedo from snow contributing to UV exposure. The more commonly used method of determining albedo is physically measuring the reflected and incident radiation using instruments that either measure the broadband spectrum (Blumthaler & Ambach 1988; Brandt et al. 2005; Reuder et al. 2007) or spectrally (Coulson & Reynolds 1971; Feister & Grewe 1995; McKenzie, Kotkamp & Ireland 1996; Lester & Parisi 2002) which can then be integrated to obtain an equivalent broadband value. It is somewhat difficult to obtain average UV albedo values for different surface types, due to the small number of papers that have pursued this topic and the differing methodology employed in each study. The differing albedo values are attributed to the method of broadband and spectral measurements, the resulting spectrum measured and the sensitivity of each instrument used. Regardless, some measurements do seem to agree, if we can be sure the description supplied of each surface can match that of another study (see Tables 1.2 and 1.3 in the following pages). Overall, the ambient levels of UV radiation can be significantly influenced by ground surface reflection and even other surface reflection.

Table 1.2 – Summary of all albedo measurements from published results.

% Albedo	(Blumthaler & Ambach 1988)	(Rosenthal et al. 1988)	(Diffey et al. 1995)	(Feister & Grewe 1995)	(McKenzie, Kotkamp & Ireland 1996)
Instrument	R-B meter	Radiometer (295nm to 350nm)	Double GaP photodiode	Spectro-radiometer (integrated up to 315 nm)	Erythemal monitor
Surface Type					
Loam				4.4	
Bare ground					3.2
Salt lake					
Sandy soil			5.9		
White sandy soil			9.1		
Sand (freshwater)	9.1		8.9	15.2	
Beach sand (dry)					
Primitive rock	3.7				
Limestone	11.2				
Flower bed			2.6		
Mown grass			1.8 (Canada) 1.2 (England) 1.4 (Saudi Arabia)		0.8-1.2
Long grass	1.3			1.7	0.5-1.0
Lawn		1.1-1.4		2.4	
Clover					0.8
Pasture	4.9				
Oats				1.7	
Rye				1.7	
Lake side water	4.8	2.7-3.9	3.2		
River side water			3		
Fresh water over gravel (0.5m)					1.8
Surf					
Snow				76.2	
New dry snow	94.4				
New wet snow	79.2				
Old dry snow	82.2				
Old wet snow	74.4				
Most ground surfaces					
Concrete (new)		14.6		9.8	15.8
Concrete			8.2		9.2
Wet concrete				8	
Concrete/pebble tile			12.4		
Gravel path			8.2		5.8
Asphalt	5.5				
Tar sealed road					6
Tarmac road			6.5 (Canada) 5.5 (England) 5.7 (Saudi Arabia)		
Tennis court	2.9				
Wooden boards (dock)			4.4		
Enamel paint (white/red)					5.1
Black butyl rubber roof					5.1
Shiny corrugated iron					18.1
Pale pink corrugated iron					
White paint – metal oxide					
Aluminium -weathered					
White fibre glass					
Glass					

Table 1.3 - Summary of all albedo measurements from published results continued.

% Albedo	(Sliney 1986) & (Heisler & Grant 2000)	(Lester & Parisi 2002)	(Reuder et al. 2007)	(ICNIRP 2007)
Instrument	IL370 radiometer (295-315 nm)	Spectro-radiometer (integrated)	Radiometer	Unknown
Surface Type				
Loam				
Bare ground	4-6 (+clay)			
Salt lake			20-70	
Sandy soil				
White sandy soil				
Sand (near freshwater)	7.1 (beach)			15-30 (gypsum sand)
Beach sand (dry)	15-18			
Primitive rock				
Limestone				
Flower bed				
Mown grass				
Long grass				
Lawn	3.7	1-3		
Clover				
Pasture				
Oats				
Rye				
Lake side water				
River side water				
Fresh water over gravel (0.5m)				
Surf	25-30			20
Snow	88			90
New dry snow	85			
New wet snow				
Old dry snow				
Old wet snow	50			
Most ground surfaces				>10
Concrete (new)	10-12			
Concrete	7.0-8.2			
Wet concrete				
Concrete/pebble tile				
Gravel path				
Asphalt	4.1-5.0 (old) 5.0-8.9 (new)			
Tar sealed road				
Tarmac road				
Tennis court				
Wooden boards (dock)	6.4			
Enamel paint				
Black butyl rubber roof				
Shiny corrugated iron		27-30		
Pale pink corrugated iron		4-11		
White paint – metal oxide	22			
Aluminium -weathered	13			
White fibre glass	9.1			
Glass	10 (100 at very large angles)			

1.2.4 Man-made influences on UV exposures to humans

While there are undoubtedly atmospheric factors that have been significantly influenced by mankind (ozone) which in turn have significant impact on humans, there are of course the more local and personal factors that man-kind has to also account for. These factors are due to the technology and equipment used, the way urban living areas are constructed, how the population spends their time, and where that time is spent. Studies that consider some of these factors (Heisler & Grant 2000) include those which take into consideration the filtering and diffusing aspect of trees in urban livings areas on personal UV exposures to people. However, first the role of human technology will be considered before looking at human behavior and influences of our built environments.

1.2.4.1 Artificial UV sources

Ultraviolet radiation is produced in one of two ways: either by a heated body with an incandescent temperature (such as the sun) or by passing an electric current through a gas such as vaporized mercury (Diffey 2002a). The excitation of the electrons within the atoms from the electric current produces wavelength emissions as the electrons return to their original states within the atom (Diffey 2002a). There are two types of artificial sources of UV radiation that mankind comes into contact with, that which is a result of welding, and lamps (which may or may not have been specifically constructed for producing UV radiation). Welding requires high temperatures to join metal components together, and as a result UV radiation is emitted predominately in the UVC spectrum and shorter UVB wavelengths (Currie & Monk 2000). There are two types of welding equipment, in which electric arc welding produces significant levels of UV radiation compared to gas welding (WHO 1994). Welding is responsible for different health effects including photokeratitis (also known as welder's flash), sunburn (Sliney 2000) and has been linked with non-melanoma skin cancer (Currie & Monk 2000) and with malignant melanoma (Gallagher & Lee 2006).

There are a variety of lamps that emit varying intensities and wavelengths of UV radiation, including germicidal lamps emitting UVC radiation primarily at 253.7 nm, phototherapeutic lamps, solar simulating lamps and “black” (UVA to the lower visible wavelengths) lamps (Sliney 2000) which are just a few of the artificial UV radiation sources available. In addition there are high pressure metal halide lamps used in curing protective coatings, ink and metal decoration and sunlamps, used as tanning devices, of which there are a number of different types as well (WHO 1994). Lamps produce UV radiation via electric current through a gas, and differing types of gas will dictate the wavelengths emitted (Bjorn & Teramura 1993). Low pressure lamps produce only certain lines in a spectrum compared to high pressure lamps (or incandescent lamps) which produce a continuous spectrum (Bjorn & Teramura 1993). Artificial tanning devices used in business that is termed solaria are one of the most contentious issues of artificial UV radiation sources. The scientific understanding of the impact of artificial tanning is still not completely known, but most scientific studies tend to show that lack of knowledge of the lamps used could potentially contribute to excessive UV exposure which could be detrimental to a person’s health through increase risk of skin cancer (Autier 2004). The uncertainty and issues surrounding lamps used in solaria was brought to higher media attention in 2007 in Australia when a young lady named Clare Oliver went public with her strong conviction that her solarium use contributed to causing her development of malignant melanoma which caused her death later that year, although it has been pointed out there is a lack of epidemiological evidence to support this claim (Gordon et al. 2008; MacKenzie et al. 2008). Nevertheless, artificial UV sources like UV radiation lamps and sunbeds used in solaria are linked to a number of health problems including strong evidence for a causative link to non melanoma skin cancer and a probable causal relationship with malignant melanoma (Gallagher & Lee 2006).

1.2.4.2 Shading

Shading is an important consequence of structures that are either natural or man-made, but even placement of natural shading structures like trees can be influential in affecting UV radiation at ground level. Most of the studies investigating the affect of shading on UV radiation is related specifically to human health, either to reduce UV exposure (Parisi, Kimlin & Mainstone 1999) or optimize UV exposure (Turnbull & Parisi 2008). Shade is particularly important for environments when the ambient thermal temperatures are naturally high, and shading provides some relief to people from direct thermal energy. However, shade may not be enough protection from UV exposure in areas of naturally high ambient UV and while in the presence of shade, a person can still obtain significant UV exposure to incur erythema (Moise & Aynsley 1999). Specifically, some man-made shade structures such as covered barbeque areas and gazebos do not provide suitable UV protection without additional personal protection (Turnbull & Parisi 2004; Turnbull & Parisi 2006). This lack of protection may be due to the significantly high diffuse UV still present within shaded areas (Parisi et al. 2000a) such as under trees (Heisler, Grant & Gao 2002), or it could be due to the type of man-made structure with open areas under the structure or transmissivity of the shading structure itself (Turnbull & Parisi 2003). In general, for both of these explanations, the total sky obstruction will be important to the total UV radiation reaching the shaded areas (Grant & Heisler 2001) which is increasingly being explored through urban canyon settings (Hess & Koepke 2008).

1.2.4.3 Occupation

With UV radiation present in the earth's atmosphere, and man's ability to produce UV radiation artificially, there is a large proportion of an individual's life in which the human body may be significantly exposed to UV radiation. This is especially true of outdoor workers. Work Cover lists the following occupations as people at risk in outdoor occupations (Workcover(NSW)):

- Building and construction workers
- Telecommunications and utilities workers
- Swimming pool and beach lifeguards
- Police and traffic officers
- Agricultural, farming and horticultural workers
- Landscape and gardening workers
- Fisheries workers
- Road workers
- Municipal employees
- Postal workers
- Dockyard, port and harbor workers
- Catering workers
- Outdoor event workers
- Physical education teachers and outdoor sports coaches
- Surveyors
- Forestry and logging workers
- Ski instructors and lift operators
- Mining and earth resource workers
- Taxi, bus and truck drivers and delivery and courier services
- Labour hire company workers

Workers who experience solar UV exposure as a part of their occupation will have all factors that cause variability in UV radiation influence their UV exposure, as well as the presence or lack of shade, the presence or lack of nearby structures and their own individual behavior (Milon et al. 2007) including the production of sweat through activity, which can increase a person's sensitivity to UVB radiation (Moehrle et al. 2000). These individual factors may be their use of personal protective equipment, but also their specific trade. Examples of the differences between UV exposure for occupation is shown by Gies & Wright (2003) and Gies et al., (Gies et al. 1995). Gies et al., (1995) found that physical education teachers received higher UV exposures than ground staff and in turn life guards, while Gies & Wright (2003) found that differences between the trade carried out in the construction and building industry contributed to variation in measured personal UV exposures. In the aforementioned studies, it was also found that the outdoor workers exceeded occupational UV exposure guidelines. Guidelines for acceptable occupational UV exposure can be obtained from a variety of sources including (NOHSC 1991; ARPANSA 2006; ICNIRP 2007) of which the latter is the internationally agreed upon guidelines. For people who might not be classified as outdoor workers, exceeding acceptable UV exposures has been measured within home workers (Kimlin, Parisi & Wong 1998) and could potentially occur for indoor workers who like to spend leisure time on weekends outside during the day (Parisi et al. 2000b). The term occupation is also sometimes used to label a type of activity, and the activity that a person might carry out in their leisure time will also influence the UV exposure they receive, as found by Herlihy, Gies & Roy (1994) who investigated such outdoor activities including swimming, tennis, sailing, walking, golf and gardening. Siani et al., (2008) investigated skiing, not just as an activity, but specifically for instructors and similar outdoor workers in alpine sites.

However, it is not just outdoor workers who experience UV exposure as part of a paid occupation. Some occupations expose workers to artificial sources of UV radiation, such as those discussed in Section 1.2.4.1. These occupations might include such activities as welding, sterilization and disinfection, photocuring, photohardening and etching, banking and commerce workers using signature verification (black lights – also used in entertainment venues), use of UV lasers, use or monitoring of sunbeds, materials inspection, phototherapy, UV photography (in dermatological applications) and even exposure to high powered lamps (used in television and theatre) of which all have some emission of UV radiation (ICNIRP 2007). Tenkate & Collins' (1997) study is an example of assessing UV exposure to welders (specifically unprotected body parts) although the study measurement techniques would have greatly underestimated total UV exposure since the techniques employed only accounted for UVB radiation (because measurement was carried out using polysulphone dosimetry (See Section 2.3.1) which does not account for a significant proportion of UVC radiation) even though high amounts of UVC is produced through the welding process. The concern with occupations that consistently expose or over expose workers to UV radiation is that workers will have an increased risk of contracting skin cancer. However, studies by Green et al., (1996) found no association with occupation and incidence of skin cancer in a subtropical environment with high ambient UV exposure, and a collective review of studies by English et al., (1997) found conflicting evidence between occupation and skin cancer, however this should be mitigated by the fact they then also counted occupational exposure as a separate entity to occupation, and found weak evidence supporting development of SCC from occupational exposure. This may be supported by an earlier study by Vitasa et al., (1990) in which the study found development of SCC with watermen (fishermen of Chesapeake Bay) was associated with higher annual UVB doses. In addition, they also found the development of actinic keratosis (abnormal skin growth caused by UV exposure) with less strength of association. So while the scientific evidence collated so far suggests occupation is not necessarily the cause of developing skin cancer, the evidence for lifetime exposures do appear to be contributory to skin cancer. This is also supported by the Working Group of the World Health Organisation's (WHO) International Agency for Research on Cancer, Working Monograph group, who found that solar radiation, UV radiation and UV emitting devices are carcinogenic to humans (El-Ghissasi et al. 2009). Just last year in Queensland the family of a man who died from malignant melanoma who worked as a carpenter and plasterer, were awarded a WorkCover payment due to the nature of his illness which was accepted to be caused due to his occupation (Hinde 2010). For people who work in an outdoor environment, there is a definite need for awareness of the effect of UV exposure and how workers can reduce their exposure to appropriate levels (ICNIRP 2007).

1.2.4.4 Reflectivity

In Section 1.2.3.7 the UV influencing factor of albedo was discussed. Albedo is essentially the reflection measured from a surface relative to the incident irradiance. Although previous studies have implied it is broadband in measurement, there are spectral measurements that have been recorded (Coulson & Reynolds 1971; Feister & Grewe 1995; McKenzie, Kotkamp & Ireland 1996; Lester & Parisi 2002). The other implication that is always associated with albedo is that it is dependent on the surface being horizontal, or normal to the down welling UV radiation penetrating the earth's atmosphere. The reflection occurring due to horizontal surfaces is particularly important for UV exposure studies, as the reflected UV radiation may influence exposure to a person on body sites that normally would be shaded or protected from direct UV radiation. These influential effects are evident in the results reported by Rosenthal et al., (1988) and Lester & Parisi (2002). Rosenthal et al., (1988) found that subjects working over more reflective surfaces (watermen and carpenters as compared to grounds men) had significantly higher ocular UV exposures which are attributed to a worker tending to either look down or at the horizon. Sliney (2000) points out that reflection from the ground dominates ocular exposure by the average use of eyes, which are normally directed towards the ground or the horizon, while the upper eye lid blocks UV radiation from the sky. Hence, snow blindness (photokeratitis) is the result of the eyes looking forward or down (or both) towards an extremely UV reflective surface. Rosenthal et al., (1988) looked at all facial features and not just ocular exposures and this is supported by Lester & Parisi (2002) in which manikins placed over shiny metal surfaces (imitating roof surfaces used in Australia) produced UV exposure enhancements to the chin over 1000%. Despite its importance, the definition of albedo has limits to its usefulness, and these limits become obvious when studies try to look at reflectance from other types of surface positions. Coulson & Reynolds (1971) differentiates between albedo and directional reflectance, taking into account the direction of the energy reflected, which leads to questioning what type of surface is being investigated, since most ground surfaces are taken as isotropic reflecting surfaces which are essentially surfaces whose reflection is considered independent on the incident irradiance.

Research on albedo measurements made from non-horizontal planes is minimal. This is surprising considering that there are studies that investigate UV irradiances on differently orientated surfaces, which clearly indicate variation in the insolation per area of UV radiation on horizontal and sun normal surfaces (Parisi & Kimlin 1999a; Philipona, Schilling & Schmucki 2001), studies that consider the influence albedo has on surrounding horizontal, inclined and vertical surfaces (Philipona, Schilling & Schmucki 2001; Weihs 2002; Parisi et al. 2003; Mech & Koepke 2004; Koepke & Mech 2005) and studies on irradiances reaching vertical surfaces (Webb, Weihs & Blumthaler 1999; Parisi et al. 2003). This may simply be because it is common to assume that reflection is constant due to initial assumption that all reflection is isotropic in nature. However, looking at measurements made by Rosenthal et al., (1988) it is clear that reflectance even on a horizontal surface is not consistent through seasons, a topic similarly questioned by Weihs (2002) through modeled data and this has led to current work carried out in this study to show that reflectance is not constant for some surfaces (Turner, Parisi & Turnbull 2008). This study showed that reflection of UV radiation in a solar UV environment is dependent on SZA, SAA, orientation and of course, surface type (Turner, Parisi & Turnbull 2008). This study shows that reflection is wavelength dependent, as also shown by Coulson & Reynolds (1971) in which they demonstrate that visible and near infrared radiation display such dependence. That particular study did look at wavelengths below 400 nm but did not emphasize the shorter wavelength importance, and a short review of their data indicates that wavelengths below 400 nm might appear wavelength independent, however some minor variations in their results indicate otherwise. This may be due to their data not extending below 310 nm. It should be noted that all the surfaces investigated by Coulson & Reynolds were natural surfaces such as loam and alfalfa.

According to Melnikova (2005) albedo does not convey any information about the reflection angle and azimuth, and the purpose of albedo is specifically for natural surfaces. This is because all natural surfaces are rough (even ice) and thus produce diffuse reflection through micro-roughness (which follow geometrical laws). Even so, albedo has shown to be inconsistent over areas of terrain with the same surface type (Weihs 2002). This lack of conformation of expected albedo behaviour and resulting measurements means that understanding UV reflectivity further will be important to understanding more about the behaviour of UV radiation. To assist in understanding why reflection should be variable even for similar types of surfaces, it is important to understand the different types of reflection.

1.2.4.4.1 Specular vs. diffuse reflection

According to Weihs (2002), directional reflection is rarely taken into account when measuring the UV irradiance on non-horizontal surfaces, as confirmed by the model developed by Wester & Josefsson (1997). What this means specifically is that most ground types reflect irregularly. This does not necessarily mean the different parts of the solar spectrum must reflect differently, but that any part of a spectrum of interest may reflect radiation specularly rather than diffusely. Specular reflection occurs when the reflected angle of irradiance is equivalent to the angle of irradiance incidence (Lenoble 1993b) known as Fresnel's Law, and the reflection occurs at the boundary of the two media (the medium in which the irradiance is perpetuated and the medium of higher refractive index it encounters). It is likely that data presented by McKenzie, Paulin & Madronich (1998) that shows changing albedo under different SZA is demonstrating this effect.

Diffuse reflection occurs when irradiance penetrates the medium of higher refractive index and is backscattered via the atoms or molecules of the medium. The direction of the backscattered irradiance does not depend on the angle of irradiance incidence, therefore the diffusely reflected irradiance is ideally reflected equally in all directions (Lenoble 1993b) following Lambert's Law. In practice, many surfaces are assumed to be perfect Lambertian surfaces and therefore reflection can be approximated on this assumption, but as stated by (Weihs 2002) most surfaces are not nearly perfect diffuse reflectors or specular reflectors but a combination of the two. This statement can be confirmed by work carried out by Ahn, Hendricks & Lee (2007) in creating diffuse reflectors for back-light units in LCD (liquid crystal display) panels. Using visible radiation ranging from 400 nm to 500 nm, they measured the diffuse and specular reflection from particle layers with different particle sizes to achieve the optimum diffuse reflector. This study showed that as particle size decreased the specular reflectance increased and the diffuse reflectance decreased. The opposite was true for larger particle sizes, with specular reflection decreasing and diffuse reflection increasing. They also noted that nanospheres were also good specular reflectors, and one might draw the conclusion that the more similar in size the particle and wavelengths of radiation are in magnitude, the better the specular reflection, whereas the less similar the particle size and wavelength of radiation, the more likely a diffuse reflector will occur. Ahn, Hendricks & Lee also found the intensity of reflected light depended on the range of angular distribution of radiation incidence, which varied somewhat with particle size but followed similar trends for all particle sizes.

Berdahl & Bretz (1997) put forward a clear explanation when it comes to considering roughness of a surface: "A smooth white coating is actually rough on the scale of the wavelength of light; that is why it appears white rather than glossy or mirror-like". However, they point out that roughness on the scale larger than the wavelengths of visible radiation is important to the path travelled by a photon – the larger the roughness, the more likelihood a photon will require more than one reflection interaction to leave the surface – thereby increasing its probability of being absorbed rather than reflected, but if it is reflected, will be independent of its incident angle. The difference between diffuse and specular reflection may be important to understanding the nature of UV reflection.

1.2.4.5 Personal protective equipment

Occupational UV exposure to workers and non-occupational UV exposure experienced by most members of the population over time means that a person will have to protect themselves from over exposure to UV radiation. This is particularly important for workers who are regularly exposed to UV radiation. There are a number of documents that outline the best safety practice of UV exposure reduction of which (NOHSC 1991; ARPANSA 2006; ICNIRP 2007) are just a few of the available guidelines and recommendations. The main forms of UV exposure reduction and personal protection include protective clothing, hat, protective eyewear and application of sunscreens however, it is considered that educating workers and the public is required in order for an individual to effectively protect themselves against over exposure to UV radiation (WHO 1994). There is research that indicates that these protective measures can be effective, such as the use of hats (Diffey & Cheeseman 1992; Wong, Airey & Fleming 1996; Gies et al. 2006a), clothing (Osterwalder et al. 2000; Gies et al. 2003; Wilson 2006, 2010), beach umbrellas (Grifoni et al. 2005), even hair (Parisi et al. 2009), whilst there are copious studies on sunscreen use and effectiveness of which the following is just a sample (Damian, halliday & Barnetson 1999; Tarras-Wahlberg et al. 1999; Autier et al. 2000). In most of these studies, the message returns to education of the public, so that any individual should be able to effectively moderate their UV exposure. However, it is only in the cases of occupational workers who frequently spend time in an UV environment that formal education begins. Unfortunately, in the many documents that are available for people to read and understand the effects of UV radiation, little is mentioned about the reflective capacity of nearby surfaces. In fact, in (NOHSC 1991) there is only a mention that metallic shiny surfaces may cause UV reflection, while (ICNIRP 2007) has one short paragraph on natural surface reflectivity.

1.2.5 Measurement of UV radiation

As has been discussed, terrestrial UV radiation is highly variable and in the case of studies that consider biological impacts, must have reasonable and accurate methods to account for UV radiation in the atmosphere over periods of time and instantaneously (Seidlitz & Krins 2006). This is especially true when one considers the differences in magnitude across the UV spectrum, which changes by six orders of magnitude over 20 nm as pointed out by Seidlitz & Krins (2006) thereby requiring sensitive instrumentation. In order to know how UV irradiance affects human skin and other features, accurate measurement of UV irradiance is important to correlating effects that are due to UV radiation and quantities of UV irradiance measurement. There are different methods of measurement and a number of different instruments that can be used to measure UV radiation.

1.2.5.1 Broadband measurement

Broadband measurement determines the total irradiance contained in a given waveband (Webb 1998a). Broadband measurement is suited to measurements made over time (Webb 1998a), and most instruments tend to be easy to use and relatively inexpensive (Blumthaler 1997). According to Blumthaler (1997), broadband detectors are suitable for measurement of albedo, which serves to emphasize the assumption that albedo was considered isotropic as discussed earlier, particularly when another of his studies (Blumthaler & Ambach 1988) had previously used the same instruments. Most broad band meters are collectively referred to as radiometers.

The other important feature of radiometers is that while integrating irradiance over a specific waveband, incorporating an action spectrum of a particular biological effect into the measurement system itself is also possible. Therefore, only the radiation of interest will be detected rather than all radiation present at the time of measurement. A common example of this type of instrument is the Robertson-Berger (RB) meter. This particular instrument uses a conversion of UV radiation to visible light using phosphor, which is detected by a photodiode (Seidlitz & Krins 2006). Interestingly, this technique of measurement creates a wavelength dependency similar to the erythemal action spectrum, hence producing an instrument that measures a portion of the UV spectrum important to many UV studies. However, the RB meter is dependent on the actual spectrum being measured. If, for example, an artificial UV source is used to mimic the solar UV output, the lower range of UVC radiation present will also affect the erythemal UV exposure recorded by the RB meter (Seidlitz & Krins 2006). In most cases an RB meter is used for measuring UV radiation outside, but there is no natural UVC radiation present outside, hence, comparing measurements inside and outside is not possible. In general radiometers tend to be used for outside measurements. At the University of Southern Queensland, UV-Biometers (Solar Light Co., Philadelphia, PA, Model 501) are used year round to measure the erythemal weighted irradiance over time, the UVA irradiance over time, and the erythemally weighted diffuse irradiance over time. These instruments are controlled by a computer and appropriate software. Seidlitz & Krins (2006) shows a schematic of one such UV Biometer, which indicates that the UV Biometers work on the same principle as the RB meter using phosphor in the system. The controlling software and computer converts the measurements made into information such as UV Index, and is accessible via the internet for anyone who requires local UV radiation and exposure information.

1.2.5.2 Spectral measurement

The downside of instruments such as radiometers, despite their ease of use and relative low cost, is that they do not give as much information about the irradiance recorded that might necessarily be required, such as information about the shape of the spectrum itself, and changes between spectral measurements due to varying factors in the atmosphere. A spectroradiometer separates the individual wavelengths detected and records the intensity for each to produce a spectral output of the irradiance measured (Webb 1998a). A spectroradiometer is made up of some core features, including input optics, a monochromator, a detector and controller or acquisition unit for the data (usually a computer) (Parisi, Sabburg & Kimlin 2004b). Each of these core features have specific requirements to produce accurate measurements of irradiance which usually conform to specifications such as those listed by Wong et al., (1995) in Parisi, Sabburg & Kimlin (2004b) such as resolution (wavelength separation), precision, sensitivity, repeatability, stray light rejection, stable detector, good cosine response of the input optics, temperature stability, ability to measure the UV waveband and stable power supply. Most spectroradiometers have a double monochromator, which induces stray light correction and improves wavelength resolution, whilst each grating is typically from 1200 to 2400 lines per millimeter. Even though there are many methods in which errors can be introduced into a spectroradiometer system (or are already present and need to be corrected for), they can be accounted for (Bernhard & Seckmeyer 1999) however, a spectroradiometer remains the most accurate way to measure spectral irradiance over a given waveband.

Despite their accuracy, the costs involved in the purchase and maintenance of such systems remain high, and their maneuverability is low (Webb 2003). A mobile scanning spectroradiometer has been in use at the University of Southern Queensland, and utilized in a number of studies (Parisi & Kimlin 1999a, 1999b), however, its size and dependency on power supplies means that there are limitations on how and where it can be used, especially when it comes to making reflection measurements from non-horizontal surfaces. It also takes time to make measurements.

Development of spectrometers with CCD detectors that are highly reduced in size compared to a spectroradiometer, whilst retaining the spectral measurement feature, has meant that measurements such as those listed above are can now be carried out with ease, over shorter periods of time. These devices have been used by the Bureau of Meteorology in Australia (Forgan & McGlynn 2010) and indicated to have reasonable measurements from 300 nm and above. Below 300 nm the stray light tends to be an issue (as there is only one grating present in the system), but as solar irradiance extends to 10 nm below this cut off, this is an error that can be accounted for in the data processing after data collection through appropriate calibration against more accurate devices.

1.2.5.3 Dosimetry

Dosimetry approximates the energy received on a surface (dose) over a given amount of time, which is similar to a radiometer such as the UV-Biometer. Dosimeters differ to a radiometer in that they do not necessarily require a power source (unless they are electronic) and require data processing after use (Webb 2003). Dosimeters can be electronic, photochemical or photobiological although one of the most commonly used is photochemical. Dosimeters (from “dose meter”) are small badgelike devices containing a photochemical material that responds or changes in some way in response to UV irradiance. In most cases this change is due to changes in the molecular structure after absorbing UV radiation, which causes changes to the characteristics of the photochemical material. In the case of one common photochemical material, polysulphone, the material changes its optical density as it responds to UV irradiance, changing its ability to absorb or transmit radiation of wavelengths in the UV spectrum, with the maximum change occurring at 330 nm. Measuring the change in absorbance of the material using a spectrophotometer at this wavelength makes use of the dosimeters relatively simple. The change in absorbance for a dosimeter is recorded for a particular time of exposure, and providing a well calibrated spectroradiometer or radiometer is also recording UV irradiance at the same time of the exposure, the change in absorbance can be calibrated against the recorded irradiances or exposures already recorded. The calibration of dosimeters is essential to calculate the corresponding UV exposures for all dosimeters exposed, since position of the dosimeter and atmospheric variations of ozone (Casale et al. 2006) may affect its exposure. Dosimeters must respond to dose rather than dose rate in order to account for changing UV irradiance (Diffey 1997). For example, a dosimeter exposed at midday will have a higher change in absorbance due to high UV exposure compared to a dosimeter exposed in the early morning, for the same time period. This is due to total dose rather than dose rate. The material was first investigated by (Davis, Deane & Diffey 1976) after it was noticed that the material “darkened” after exposure to UV radiation, and has since been used in dosimetry ever since by further exploring its characteristics (Diffey 1986; Diffey 1989; Webb 1995; Wong et al. 1995; Taylor et al. 2002; Kimlin 2003) and is used in many studies involving the measurement of UV exposure due to the fact that a dosimeter is small, able to be placed at any orientation, and can be located in places that larger equipment would not normally be able to be used in. Dosimeters are commonly used in assessing personal UV exposures (Diffey & Cheeseman 1992; Herlihy, Gies & Roy 1994; Tenkate & Collins 1997; Parisi & Kimlin 2000; Lester & Parisi 2002; Gies & Wright 2003; Gies et al. 2006b; Milon et al. 2007; Downs & Parisi 2008; Turner & Parisi 2009) but have also been used for assessing UV exposure to plants (Parisi et al. 2010a; Parisi et al. 2010b) and even for UV exposure under water (Dunne 1999; Schouten, Parisi & Turnbull 2007, 2009). When used in comparative situations, dosimetry can be an excellent method to account for changing factors in an environment such as the effect on shade (Turnbull, Parisi & Downs 2006; Turnbull & Parisi 2008) in which manikins of the same shape and style, one placed in the shade and the other placed in full sunshine, with attached dosimeters, can compare the effective exposure a person may experience in these situations. When studies like these are carried out, another property is taken into consideration, which is termed the dark reaction, a condition in which the dosimeter, once removed from a UV environment, will continue a minimal change in absorbance despite being in a UV free environment. After 24 hours this amounts to approximately a 4% change (Davis, Deane & Diffey 1976). This effect can be taken into consideration by standardizing the time of measurement after each exposure (Diffey 1989). Polysulphone dosimeters are not affected by temperature (Diffey 1989).

1.2.6 UV reflectivity

The reflection of UV radiation in the terrestrial environment has been addressed already in the previous section discussing factors that influence UV radiation levels at the earth's surface. However, as pointed out in the previous section, knowledge about the nature of UV reflectivity seems to be somewhat conflicting, specifically in how UV reflectivity should be measured and what is actually happening physically. In a previous section, the definition of albedo and its context of use was presented, and found to have potential limitations when UV reflectivity measurements are required from surfaces other than the horizontal plane. This section seeks to bring as much knowledge about reflection in the UV spectrum together with how UV reflectivity has been used in research, in order to be able to consider the research questions presented in a later section as effectively as possible.

1.2.6.1 Historical usage and measurement

As noted previously, the measurement of UV reflectivity for natural surfaces (therefore known as albedo in this context) goes back to 1925 for published information (Angstrom 1925), but reflection in the UV spectrum was actually being investigated earlier in the early 1900s, as indicated by Hulburt (1915) noting the studies carried out in 1900 to measure the reflection of UV radiation from a variety of metals and metalloids made into thin films. The work by Hulburt shows a thorough investigation of UV reflection ranging in wavelength and metal type, starting at wavelengths below 200 nm and reaching up to 350 nm using steps of approximately 6 nm. Measurements made around the 300 nm interval showed reflection no lower than 10%, but with a general average of 20 to 50% with the exception of aluminium (60%) and silicon (~75%). Hulburt declares that aluminium appeared to be the most efficient UV reflector apart from silicon, and the work presented is also mindful of his method of reflection measurement, where, rather than measuring angles of incidence either equal to the normal or 1° to 2°, which was the norm at the time, the angle of incidence was maintained at 18°. Later in the paper he notes that small deposits of aluminium were found in the silicon films.

This study was later followed by more studies on a variety of surfaces and types (Taylor 1934, 1935), but gradually narrowed to a more focused range of study, where the use of aluminium reflectors was used in hospital operating rooms (Edwards 1939) but as aluminium became harder to source, other metals were again studied (Taylor 1941). In addition, the use of reflectors were used in germicidal applications, but then the focus drew to the UVC spectrum and therefore artificial sources of UV radiation (Luckiesh 1946; Luckiesh & Taylor 1946). In addition to metals and coatings on metals, paints and pigments were explored for their reflectivity, possibly in order to identify paints that reflect well in the visible radiation to increase lighting in buildings but minimize UV radiation reflection (Stutz 1925; Wilcock & Soller 1940).

1.2.6.2 Current knowledge and measurement

Reflection measurements in the UV spectrum have been carried out in the later decades of the 1900s, but not as the main focus of a study, rather as addition to a spectral analysis that spans the entire solar terrestrial spectrum of UV, visible and infrared. In Pomerantz et al., (1999) spectral analysis of an acrylic white coating on a steel surface shows UV reflection ranging from 0 to around 35%, but because the UV is presented in proportion to the visible and infrared, it almost seems to be inconsequential and the plot itself allows very little interpretation of what is occurring in this part of the spectrum. Berdahl & Bretz (1997) interestingly use exactly the same graph with a number of other analyses, however, to the eye the UV reflection data presented appears exactly the same in each case, regardless of surface type. Berdahl & Bretz also make a claim that corrugation of a surface such as metal sheeting will reduce measured reflectance compared to a completely flat surface (albeit a very small sample) but offer no evidence to support the comment, only referring to a model developed for rough surfaces that may evaluate this claim. Parker et al., (2000) have performed a thorough analysis of reflective properties of the entire solar terrestrial spectrum on thirty seven different surface types (including colour variations of the same surface types). The resulting measured UV reflection is the integrated reflectance from 300 nm to 400 nm using an integrating sphere on a Beckman 5240 Spectrophotometer. For the multiple surfaces in different colours, the data presented shows significant variation in the UV reflectance values in somewhat similar proportions to variations in the visible reflectance measurements. This seems unusual by indicating that colour can influence UV reflection, although it could be due to how the colour is created at a microscopic level. Parker et al., have also looked at coatings on these surface types, which are primarily used to reduce thermal absorption.

In solar energy applications, the use of UV reflectors are demonstrated by using aluminium as the main component of a reflector (Malato Rodriguez et al. 2004) with some extra acrylic coatings increasing reflectivity up to 87%. Optical properties of solids also provide information on UV reflectivity of metals such as that of silver (Fox 2001a), which has significantly lower reflectivity in the UV spectrum compared to the visible or infrared. The same text works a problem surrounding zinc and the use of plasma frequencies and electron densities, and after working through this problem we find that below this plasma frequency, UV and visible radiation is reflected by zinc (Fox 2001b) although intensity amounts are not explored. It is no wonder then that galvanized surfaces (coating a surface in zinc) produces UV reflective surfaces. Some optical texts will have a small section on the optical properties of metals but like Hecht (2002) only consider reflectivity in terms of visible radiation.

Snow is the highest natural known reflector of UV radiation (Sliney 1986) and has been investigated in a number of studies, although the important aspect that all studies point towards is the variability of UV reflection from snow. UV reflection will differ according to type: new, old, and level of snow melt present (Blumthaler & Ambach 1988; McKenzie, Paulin & Madronich 1998).

1.2.6.3 Albedo vs. reflectivity

Whilst not UV specific, there are numerous studies that investigate the effect of "urban heat islands" and resulting albedo from solar radiation. The central concept behind these studies is the reflectivity of solar radiation within the urban landscape. Aida (1982) built a scale model of an idealized urban structure out of concrete and found that factors such as SZA, seasonality and direct and diffuse radiation components were just as important as building size and spatial areas, and the follow up study by Aida & Gotoh (1982) decreases in the urban albedo with increasing irregularity of the urban structure. In fact the conclusions from this study can draw very similar parallels with the study by Ahn, Hendricks & Lee (2007), despite the fact that the latter study is working on a micro scale and the former study is in the macro scale. These studies are followed by further attempts to devise better models to understand radiative transfers within urban structures, and studies also starting to differentiate between a broad scale albedo and a specific surface type albedo. Fortuniak (2008) is one such paper using this differentiation, although their determination of a specific surface type albedo is assumed for simplicity which rather negates the need for separate surface type albedo. It also emphasizes the difference between diffuse and direct reflections (Lambertian surfaces rarely existing in real structures) despite not accounting for this in their model. This might be because previous studies had looked briefly at this issue (Tsangrassoulis & Santamouris 2003) in glazed surfaces as opposed to non-glazed surfaces, which interestingly only then looks at the resulting effective albedo rather than specific surface type albedo. It would seem that the use of albedo and reflectivity really need to be defined as separate entities. A much earlier and more preliminary study by (Terjung & Louie 1973) on the urban heat island effect gives a conclusion that is the precursor to the aforementioned studies: vertical surfaces may be the key element to the urban heat island effect. We can use this information to postulate on UV reflection from vertical surfaces. For example, in McKenzie, Paulin & Kotkamp (1997) higher UV irradiances were measured on normal-to-sun surfaces than horizontal surfaces, and it is possible that vertical surfaces may show the same variances in reflectivity, which leads to the scope of this study.

1.3 Research objectives

The objectives of the research undertaken are:

1. Quantify and analyse albedo due to vertical surfaces for a variety of factors, solar zenith angle, orientation and surface type, and verify there are quantifiable differences between albedo due to horizontal, inclined and vertical surfaces. Ranking of albedo will be applied to all surface types, identifying the most UV reflective surfaces. Quantification of albedo will also include measurements of materials in the field, such as building walls, and multiple surface sites where there is more than one surface present in the immediate vicinity of a vertical surface.

2. Determine if there is a relationship between the albedo due to a vertical surface and the albedo due to a horizontal surface, should they be different to each other. Previous studies have investigated irradiance falling on such surfaces, but not for albedo. This would be important for monitoring changes in albedo, particularly due to factors such as solar zenith angle.
3. Quantify the damaging and beneficial biologically effective UV exposure to anatomical sites on humans due to albedo from vertical, inclined and horizontal surfaces for variations in solar zenith angle, orientation and surface type and compare to that received from a non reflective vertical, horizontal or inclined surface, or no nearby surface at all. Personal dosimetry will be used to quantify this information, and the data collected will be calibrated to quantify both the erythemal biologically effective UV exposure and the vitamin-D biologically effective UV exposure.
4. Convert the above information into UVI factors (as an extension of the third project aim). For example, the UVI for a person standing near a wall may increase/decrease from the UVI recorded in an open area. This factor could be applied to the standard UV Index and be understandable to the public.
5. Investigate the changes in albedo due to vertical surfaces, by exploring the different components of albedo, specifically that of direct and diffuse UV radiation in relation to solar azimuth and zenith angles. Depending on the orientation and the type of the surface, the proportion of direct to diffuse UV will change. This information will contribute to knowledge about diffuse radiation in the atmosphere.

2 Methodology

2.1 Overview

In order to quantify the UV reflective capability of vertical surfaces in the urban environment and their ability to influence biological exposures, two types of techniques were required, namely dosimetry and spectral UV irradiance measurement. Previous work on measuring albedo from roofing surfaces (Lester & Parisi 2002) and measuring albedo from a wall (Parisi 1999) indicate that these methods are the most effective at quantifying the required information.

2.2 Quantification of UV reflection from metal surfaces due to multiple factors

A number of factors will have to be taken into account to determine the reflective capability of surfaces. The most important factors in this section are surface orientation and direction, SZA, and surface type. The initial measurements for UV reflection quantification were carried out on an archery field at the University of Southern Queensland, Toowoomba, Australia (27.5° S, 151.9° E) in 2007. A metal frame was constructed to support a 1 m × 1 m size vertical sheet, of either a trapezoidal profile or corrugated profile sheet metal in order to simulate the exterior wall of a building or a fence. A second piece of sheet metal of the same size was attached to the other side of this metal frame, inclined at 35º to the horizontal, to simulate the sheet metal on the roof of a building with an average building design standard. Both sheets were separated by the frame with sufficient distance between each sheet to prevent shading (Figure 2.1).

Figure 2.1 - Experiment set up for reflected irradiance measurements for various SZA and azimuth for a vertical sheet and a sheet inclined at 35° to the horizontal. The photo on the right also shows the horizontal sheet. Ground UV reflectance 1% measured for set up on the left, up to 3% for set up on the right.

Eight types of trapezoidal metal sheeting and two types of corrugated metal sheeting were used (supplied by Metroll, Toowoomba). One of each profile type was made with zinc aluminium coated steel. In the trapezoidal profile a second sheet of this same type had a heat reflective coating applied (Insultec, supplied by The Australian Insulation Super Store, Brisbane) and was greyish white in colour. The rest of the trapezoidal sheeting was coloured paint coated steel in cream, beige, dark green, medium blue, dark red and black. The distance between the ridges on the corrugated steel waves was 7.8 cm and the height difference between a trough and a peak was 1.7 cm. The height difference between the top and bottom of the trapezoidal profile was 2.9 cm. The distance between the centres of the high ridges was 19 cm. Both sheet types have the ridges equally spaced across the surface and are symmetrical. The surface ridges were aligned top to bottom for inclined and vertical surfaces which holds with general building practices, and north to south for the horizontal surface.

The UV irradiances required to calculate UV reflectance were measured spectrally with an EPP2000 spectrometer (StellarNet, Florida, USA) with a detector based on a CCD array with a concave holographic grating with a groove density of 300 g/mm. The spectrometer has a slit width of 25 μm to give a resolution of less than 1 nm. Wavelength and irradiance calibration of the EPP2000 was undertaken by employing the 365 nm mercury spectral line and a 150 Watt quartz halogen lamp with calibration traceable to the National Physical Laboratory, UK standard. A cosine receptor connects to the input of the housing for the array via a two meter fibre optic cable. The EPP2000 measured spectral irradiance from 300 nm to 700 nm in 0.5 nm steps. As a result of this waveband, visible irradiance information was collected also. The integration time was 24 ms and averaged over 25 scans. The receptor was held in place using a lab stand with a 0.5 m arm and clamp. The arm held the receptor away from the main body of the lab stand, therefore reducing the amount of shadow that might fall on the metal sheeting during measurement. The lab stand, arm and clamp were adjustable so that the reflected UV irradiance of the horizontal, vertical and inclined surfaces was recorded at 0.5 m from the surface of the metal sheeting, with the sensor facing along the normal to each type of surface. The distance of 0.5 m was chosen because this was approximately an arm's length in distance from the metal surface. For example, if a person working outdoors was working in a building situation, such as construction of a wall or roof, this would be a reasonable estimate of the distance a person could be from the wall. The distance of 0.5 m was tested to determine if the sky view beyond the sheet would affect the reflected irradiance measurements. The test compared the reflectivity at distances that were close enough to the sheet so that the cosine receptor would not receive any irradiance other than that from the sheet, to that at longer distances. The distances employed were 0.1 m, 0.2 m, 0.3 m, 0.4 m, 0.5 m and 1.0 m. It was found that for surfaces facing the sun, the sky view had little effect on the spectral reflectivity recorded over these short distances. As the distance between the surface and sensor increased, the spectral reflectivity decreased in intensity. The sky view only affected surfaces that were facing away from the sun. Since the pieces of sheeting were small in comparison to a building, direct UV spectral irradiance was not blocked in the area surrounding the created wall. This direct UV irradiance affected the results recorded by appearing to increase the spectral reflectivity as the distance between the surface and sensor increased. Data that was collected for these surfaces usually produced a reflectivity greater than 1.0, indicating the data was flawed since no surface can reflect more irradiance than is incident upon it. As a result the data collected showing these types of results was discarded. This flaw occurred the most for distances of 1.0 m, whereas at 0.5 m the sheet sometimes shaded the sensor, thus allowing the sensor to record only reflected irradiance. The decision to choose a distance of 0.5 m from the surface was maintained through to the rest of the studies carried out for this project.

To account for the SZA four series of measurements were carried out for a SZA range over a day (for example between 35.3º and 73.4º for one sheet metal type). Early morning measurements began at 8 am local time, mid-morning measurements began at 10 am, midday measurements at noon and mid-afternoon measurements at 2 pm. Each series of measurements lasted approximately forty minutes. Each measurement made had the corresponding local time recorded, so that the appropriate SZA could be calculated.

In order to be consistent with the orientation, the metal frame was placed so that the vertical face was oriented towards geographical north initially (and therefore the inclined face was oriented to the south).The horizontal sheet was placed a short distance away from the metal frame to prevent shading. The metal frame was rotated and measured with the vertical face oriented to the west, south and east (the inclined face was oriented to the east, north and west). In the Southern Hemisphere, the north facing surface receives the most UV irradiance compared to surfaces facing west, south and east.

The spectral UV reflectance was measured by recording the global spectral irradiance on a horizontal plane, then recording the reflected spectral irradiance for a given surface and taking the ratio of the spectral irradiances at each wavelength. In the published account of this data (Turner, Parisi & Turnbull 2008) (also see Appendix 8), the measurement was referred to as RRG (Ratio of Reflected irradiance to Global irradiance) rather than albedo due to the need to be able to compare reflectivity from different oriented surfaces as discussed in the literature review. Each different oriented surface was measured for global spectra and reflected spectra, at each position (vertical, horizontal and inclined) throughout the day. Each measurement was repeated to allow averaging of the results.

At the time of the study, the average RRG_{UVB} was determined by integrating the spectral data from 300 nm to 320 nm in 0.5 nm increments for each reflected and global spectral irradiance measurement before calculating the ratio. The reflectivity was then averaged according to the influencing factors: surface type, position, orientation and SZA.

Measurement of the reflected UV radiation from urban surfaces was first carried out in the cooler seasons of the year, namely Autumn and Winter (March through to August in the southern hemisphere), due to the ideal weather conditions, which is clear with low cloud coverage, in order to reduce confounding the measurements of

UV reflection. Measurements were then carried out in spring to compare, while at the same increasing the SZA range. Weather conditions through late spring onwards tend to be unsettled affecting data collected.

2.3 Quantification of biological effect of UV exposure due to UV reflective surfaces

2.3.1 Dosimetry

Photochemical based dosimeters have been used for many years to evaluate UV exposure. Polysulphone is the photochemical product used predominantly for UV exposure measurements and its use as a dosimeter has been documented from its very initial use (Davis, Deane & Diffey 1976) and over time (Diffey 1989; Webb 1995; Wong & Parisi 1999) to today (Colucci 2007). The action spectrum of polysulphone approximates the erythemal action spectrum and therefore is a suitable device to measure the biologically effective UV exposure on a surface.

Polysulphone was prepared in the form of a thin film sheet at the University of Southern Queensland (Toowoomba, Australia). Polysulphone sheets are cast using a solution of polysulphone pellets (Sigma-Aldrich Pty. Ltd., Australia) and chloroform in the ratio of 3 g to 25 mL. All preparation and casting was carried out in a fume cupboard. The solution was left for as little as one hour in order to combine (and reduce the pellets to liquid form), but the best result was achieved by leaving the solution overnight and softly mixing the next day to check consistency. The solution was then applied to a glass plate using a specifically designed casting table. The glass plate was levelled before use, and the polysulphone solution was spread over the entire glass plate using a motor controlled blade. The blade height was set at 100 μm (using a feeler gauge) which can produce a sheet with a minimum thickness of 20 μm. The sheets were left to dry for a minimum of 15 minutes but it was usual to leave the sheet for one to two hours before removal to ensure all chloroform fumes had dispersed. The sheet was removed from the glass plate by spraying a stream of distilled water on the end of the sheet where the blade started from. If no polysulphone went over the edge of the glass plate, the water would cause the sheet to start to lift from the glass plate due to the surface tension of the water. A sharp blade run along the edges of the glass plate was usually required to assist in the removal of the sheet. This was done carefully and the sheet was placed on and under paper towel to dry. A light evenly portioned mass such as a folder was placed on top of the paper towel and kept the sheet flat, preventing the sheet from curling. The polysulphone sheet was then stored in a UV free environment until required.

A dosimeter is made by cutting polysulphone into 2 cm × 2 cm pieces and mounting on a plastic holder (3 cm × 3 cm) with an aperture of 1.2 cm × 1.6 cm. The absorbance of each polysulphone dosimeter was measured using a spectrophotometer (UV-1601, Shimadzu & Co, Kyoto, Japan) before and after use, and the change in absorbance was calculated from these measurements. The spectrophotometer has an error of ±0.004%. Maximum change in absorbance for polysulphone occurs at 330 nm (Diffey 1989; Parisi, Sabburg & Kimlin 2004a) and all absorbance measurements are made at this wavelength. The spectrophotometer has a rotating mount for the dosimeter. The dosimeter absorbance was measured at four points over the surface and the values averaged, thus allowing for variations on the surface and the thickness of the photochemical material. Creation, storage and measurement of the dosimeters were carried out in UV-free environments.

To determine the biologically effective UV exposure that corresponds to this change in absorbance, the dosimeters were calibrated against a scanning UV spectroradiometer (model DTM300, Bentham Instruments, Reading, UK), located on a roof top at the University of Southern Queensland. The spectroradiometer scans from 280 nm to 400 nm in 0.5 nm steps every five minutes of every day from 5.00 am to 7.00 pm. An air conditioning unit stabilises the temperature within the environmentally sealed box to 25.0 °C ± 0.5 °C. The spectroradiometer makes both global and diffuse scans, alternating so that a global scan occurs at the 0, 10, 20, 30, 40 and 50 minute points and the diffuse scan occurs at the 5, 15, 25, 35, 45 and 55 minute points throughout the day.

A dose response is built by calibrating the biologically effective UV exposure against the change in absorbance and correlating the data to produce a mathematical relationship. This was carried out by exposing a series of dosimeters on a horizontal plane to sunlight for varying time periods and matching them with the appropriate biological effective UV exposures. To calculate the biological effective UV exposure the data collected by the spectroradiometer was then weighted against an appropriate biological action spectrum, and integrated over the scanned wavelengths for each scan made. Simpson's rule, a numerical integration method, was used to calculate total exposure over the given period of time from the global spectral measurements made every ten minutes. The biologically effective UV exposure was weighted using the action spectrum for erythema (CIE 1998). The unit of measurement used in this study is the standard erythemal dose (SED) which is equivalent to $100 Jm^{-2}$ of erythemally weighted irradiance. In addition the biological action spectrum for vitamin D_3 production (CIE 2006) was also used for comparisons of erythemal exposure to vitamin D_3 weighted exposure for initial calculations, but was not continued when the measured exposures of each weighted system was extremely similar, and therefore any ratios also produced similar results. However, it is possible to calculate the vitamin D_3 weighted UV exposure if it is required by employing the methods suggested by Pope et al., (2008). The relationship between biologically effective UV exposure and change in absorbance was then used to quantify the UV exposure received at various sites and orientations. Calibration curves were calculated for every hour of exposure. Polysulphone dosimeters have a variation in dose response calculation of about 10% up to a change in absorbance of 0.3 (Diffey 1989). As the maximum for a dosimeter in this study did not exceed this change in absorbance, the error in the calculated erythemal exposure for each dosimeter is 10 %. For the relative measurements, the error can accumulate to approximately 20 %.

2.3.2 UV exposure measurement

2.3.2.1 Walls

The variation in UV exposure measurement over the human body is measurable using manikins with dosimeters attached at various anatomical sites simulating a person receiving UV exposure. To determine the influence of vertical surfaces over biologically effective UV exposure, a manikin with dosimeters was placed in front of a constructed wall. The potential influence is judged compared to controls. Therefore, at the same time, a manikin is placed in front of a non-reflecting constructed wall and a third manikin is placed in the open away from any wall or shading object. A similar technique has been used to quantify the effects of hats (Diffey & Cheeseman 1992; Gies et al. 2006a).

A head form in each of the above situations was prepared for each metal surface type and exposed from 8 am to 3 pm. The exposure times were staggered hourly over two days due to the lengthy set up and measurement process. Measurements were taken from 8 am to 9 am, 10 am to 11 am, 12 pm to 1 pm and 2 pm to 3 pm on one day and measurements taken from 9 am to 10 am, 11 am to 12 pm and 1 pm to 2 pm on the second day with the polysulphone dosimeters replaced after each hour of exposure in order to determine if there was variation in influence to UV exposure during different periods of the day. If the atmospheric conditions for each day of the two days of exposure per metal sheet type were not similar, the experiment was carried out when more appropriate weather was available.

The constructed walls consisted of two pieces of each type of metal sheeting bolted together side by side and supported by a steel metal frame. The dimensions of the constructed wall were 1 m high and just under 2 m wide (Figure 2.2). The types of metal sheeting investigated were: zinc aluminium coated steel trapezoidal sheeting, pale green coated steel trapezoidal sheeting, zinc aluminium coated steel corrugated sheeting and cream coated steel corrugated sheeting. These sheets were selected for their frequency of use in building construction, and from the results obtained in Section 2.2. The ridges were aligned vertically, which is common building practice for these surface types due to the strength they provide. Each constructed wall faced north, as northerly facing walls in the southern hemisphere will receive the most solar radiation during the day, provided shading does not occur.

Figure 2.2 – Constructed walls and head forms (left) and standalone head form (right) with shading due to the position of the sun.

The secondary non-reflective constructed wall was created by placing black felt over the same type of metal sheeting to inhibit UV reflectance. The set up for this wall was the same as the reflecting wall, with the black felt attached to metal sheeting with clips to retain the ridged feature of the sheeting.

The UV-reflecting and the non-UV reflecting walls were constructed in an open area at least 10 m away from any other structures. The head forms were placed at 0.5 m (at the position of the shoulder) from each wall, with the facial features oriented towards the wall. The third head form was placed in the open, with no nearby structures, oriented in the same manner and facing the same direction as the head forms near the constructed walls. Each head form had thirteen polysulphone dosimeters attached at specific facial or body features. These features were the top of the head, forehead, nose, chin, chest, back of head, back of the neck, cheeks, ears and shoulders. In order to approximate the UV exposures measured as accuately as possible, a dosimeter calibration was carried out at the same time as each hour of exposure, with a dosimeter removed at each ten minute interval over each hour. Each session of UV exposures is therefore calibrated for that specific day’s atmospheric conditions.

2.3.2.2 Walls at vertices – corners

The same technique outlined in Section 2.3.2.1 was used to investigate if the effect of vertices within a wall structure would influence UV exposure differently to UV exposure obtained near a wall structure with no vertices. One type of vertical junction was used, specifically the inside of a right-angled corner. There are a variety of vertical junctions that a person may be influenced by including standing outside a right-angled corner, or a corner that is not at right angles, or inside corners that are not right angles. The selection of the situation of a person standing inside a right angled corner was chosen due to the appropriateness of the situation. In construction, a person may stand inside the corner of a right angled junction because they are constructing the building, or they may be working at a point where an outside wall meets another wall (due to building design or positions of fences which can be constructed of the same material). A person standing outside a right angled corner would also be experiencing the same sort of UV exposure a person may obtain from a standard vertical wall, therefore a simulation experiment would simply repeat the experiments already carried out for vertical walls. In the situation of non-right angle corners, this is considered an uncommon building practise, and therefore it was felt this study should reflect common building practices. Therefore, the simulation of a person standing inside a right angled corner (facing one wall) was chosen (Figure 2.3).

The experiment was carried out for situations of full sun, since shading would significantly affect the influence of UV exposure in comparison to the UV exposure obtained near a vertical wall. The walls of the corner faced north and east from 8 am to 12 pm, and then the corner was adjusted so that it faced north and west from 12 pm to 4 pm. A head form placed in a non-reflective corner was used as a control, as was a third head form placed in the open as shown in Figure 2.3. The corners were constructed from two types of metal sheeting: zinc aluminium coated steel and pale green coated steel in the trapezoidal profile.

Figure 2.3 – Measuring UV exposure to a head form inside a right angled corner wall junction.

2.3.2.3 Wall orientation – vertical, inclined and horizontal

The same techniques used in Sections 2.3.2.1 and 2.3.2.2 were used to compare the biologically effective UV exposure received from the proximity to vertical, horizontal and inclined surfaces and determine if it is possible to receive more biologically effective UV radiation from one orientation of a surface than another. This situation was more difficult to achieve compared to vertical surface analysis. Frames were constructed to attach the head forms to in order to lift the head forms to a position above inclined and horizontal surfaces that would be similar to the distance of the shoulder to the surface used in the vertical position assessment (Figure 2.4a). Shading of the surfaces due to the head form itself became as issue in this experiment (Figures 2.4b & 2.4c) which was dependent on SZA and azimuth. Two types of metal sheeting were used in this experiment: zinc aluminium coated steel and pale green coated steel in the trapezoidal profile. Sheeting was oriented towards the north, where the horizontal and inclined surfaces had their ridges

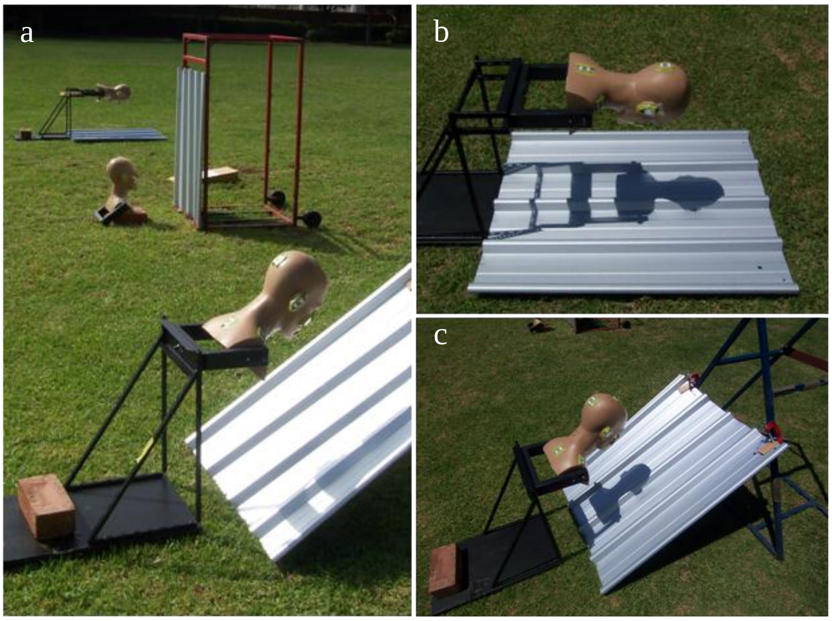

Figure 2.4 - (a) UV exposures measured for vertical, inclined and horizontal surface fixtures. (b, c) Shading caused by head form placement.

indicating the direction (Figure 2.4a). The inclined surface was placed at an angle of 35° to the horizontal.

2.3.3 Spectral reflectance measurement

Section 2.2 outlined the technique used to measure UV exposure using an EPP2000 spectrometer and Section 2.3.2 outlined the set up for a variety of different UV exposure measurements. Concurrent spectral irradiance measurements were carried out during these UV exposure experiments. The global irradiance, total irradiance (sensor directed towards the sun's position in the sky), reflected irradiance, the irradiance normal to and from a surface direction (without a surface) were measured during most of the UV exposure experiments. The reflected irradiance from the non-reflecting surface was also measured for comparison purposes. Figure 2.5 represents these measurements diagrammatically.

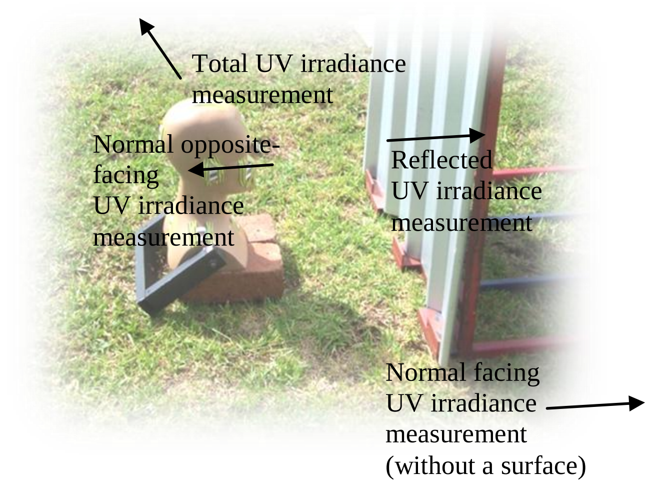

Figure 2.5 - Sensor direction for irradiance measurements.

The EPP2000 was used for initial measurement. The repeated measurements were made using a USB4000 Plug-and-play Miniature fibre optic spectrometer with a diffuse sensor (Ocean Optics, Inc., USA). This machine was employed due to the EPP2000 spectrometer breaking down and the fault unable to be fixed satisfactorily enough to obtain reasonable spectral results in comparison to the scanning spectroradiometer (model DTM300, Bentham Instruments, Reading, UK). The USB4000 has been used successfully in measuring spectral irradiance on plant leaves and has an average of ±10% uncertainty for the integrated UVB waveband compared to the Bentham spectroradiometer (Parisi et al. 2010a).

The USB4000 spectrometer has a bandwidth of 200 nm to 850 nm, with a 600 line blazed grating, a blaze wavelength of 400 nm and an opening slit width of 25 μm. As a result of these specifications the spectrometer measures in average integrated steps of 0.2 nm. The measurements made by the USB4000 spectrometer were calibrated against the Bentham spectroradiometer, using the following method.

2.3.3.1 Calibrating the USB4000 spectrometer

The USB4000 spectrometer measures in 0.2 nm integrated steps from 200-850 nm while the Bentham spectroradiometer measures in 0.5 nm integrated steps from 280-400 nm. Since the UV waveband under investigation is the same as that measured by the Bentham spectroradiometer, the same bandwidth measurements using the USB4000 could be calibrated. To calibrate this bandwidth, measurements were made throughout a day of clear weather with the USB4000 at the same times that the Bentham spectroradiometer made measurements during the day from 8 am to 4 pm. The measurements from each machine were then compiled according to the time of measurement. Due to the difference between the integration steps, the data obtained from the Bentham spectroradiometer was re-integrated to 0.2 nm steps using basic mathematical principles. For each value recorded at each 0.5 nm step from the Bentham, and the neighbouring step value, were interpolated to intervals of 0.05 nm. Unfortunately, the USB4000 integrated step intervals were not exactly 0.2 nm, rather an average of 0.21 nm and 0.22 nm steps. This meant that calibration against the Bentham required the wavelength intervals to match. By interpolating the intervals down to 0.05 nm, the wavelength steps that were not matched to the USB4000 steps could be removed while retaining the integrity of the measurements of the Bentham. For each measurement made with each instrument, the UV irradiances recorded at each wavelength integrated step were compared. From this comparison a multiplication factor was obtained and then averaged across all measurements during the day. This resulted in an average multiplication calibration factor that could be then applied to measurements made by the USB4000 to correct any spectral errors in its waveband. Once the USB4000 measurements have been calibrated, the USB4000 has an average of ±10% uncertainty for the integrated waveband of 300 nm to

400 nm compared to the Bentham spectroradiometer which is the same error as that found in (Parisi et al. 2010a).

2.3.3.2 Characterising spectral reflectance

Spectral reflectance measurements made originally in 2007 with the EPP2000 were confined to measuring the global irradiance and reflected irradiance of each surface type. The global irradiance is defined as measurement of all downwelling irradiance when the sensor is aligned normal (upright) to the hemisphere of the sky. The reflected irradiance is measured when the sensor is aligned normal to the surface (the two faces are parallel). The reflectivity of the surface was then calculated to be the ratio of the reflected irradiance to the global irradiance at each integrated step.

Before the EPP2000 was put out of commission, further reflectance measurements were then carried out as the ratio of reflected irradiance to direct irradiance. Total UV irradiance measurements were measured when the sensor was normal to the position of the sun in the sky (therefore accounting for higher relative percentages of direct irradiance as compared to that obtained in a standard global irradiance measurement). In order to quantify if UV exposure influence was not due more to diffuse UV irradiance than reflected UV irradiance, measurements were taken with the sensor oriented normal to a surface orientation (facing and opposite facing) without a surface being within the range of the sensor. A ratio of the reflected irradiance from a surface, to the UV irradiance measured in the same orientation without a surface, was calculated. This was measured for both orientations of facing surface and opposite facing surfaces. The spectral reflection for a number of other surface types located on buildings around the University of Southern Queensland's campus were also carried out when weather conditions and position of the sun made the measurements feasible.

2.4 Quantification of relationship between horizontal and vertical reflectivity

A study carried out by Webb et al., (1999) compared the UV irradiance falling on a vertical surface to irradiance falling on a horizontal surface, and established a relationship between the two. Measured UV reflectances made in Section 2.3.2.3 from horizontal and vertical surfaces were investigated for a similar relationship. The erythemal weighted reflection from a vertical and a horizontal surface made at the same approximate SZA and SAA on the same day were plotted against each other for all available data and a corresponding function was derived from this data. The same procedure was carried out for vertical and inclined erythemal weighted reflection.

2.5 Establishing a UVI factor for UV reflective surfaces

Each time an exposure measurement was carried out, the UV index was also calculated by using data collected from a UV-Biometer (Solar Light Co., Philadelphia, PA, Model 501) on the campus of the University of Southern Queensland. The UV-Biometer takes erythemal weighted exposure measurements over five minute intervals and from this measurement calculates the corresponding UVI. Exposure measurements near a wall uses an interval of one hour, therefore, there are twelve calculations for the UV Index per hour of measurement. The average UVI for each hour interval of UV exposure measurement was calculated. The average exposure measured per head form is then plotted against the average UVI for that hour interval. A trend line was applied to the resulting data series. Comparing the function for each trend line results in an average modification factor due to the presence or lack of a wall according to the standard UVI (on a horizontal plane).

2.6 Resolving contributions of direct and diffuse UV radiation to effective reflectivity measurements

The direct UV reflection and the diffuse UV reflection were measured, and the resulting reflection values were compared. The technique to measure diffuse UV reflection included attempting to block direct UV irradiance from the sun using a small shadow band, and using the same shadow band to attempt to measure diffuse reflected UV from the surface on a clear day. However, this produced erratic results, as the “shadowing” of the reflected component left overhead solar irradiance able to affect the diffuse measurement. A shadow band blocking both overhead solar irradiance and direct reflected irradiance proved difficult to determine if all directly reflected irradiance was accounted for, and therefore was abandoned in favour of the following technique. This technique to measure diffuse UV reflection was to carry out reflection measurements on a cloudy day, when the sun is sufficiently obscured by unbroken cloud. Measurements made on a day with broken cloud may be affected by the ability of cloud to enhance UV irradiance at the earth’s surface due to scattering and absorption.

3 Results

3.1 Overview

The results obtained from data collected are presented here. Preliminary spectral reflection measurements were started in 2007. The method was refined in 2008 and further UV reflection measurements were carried out alongside some of the UV exposure measurements to explore this problem. The results will be discussed in detail in Chapter 4.

3.2 Quantification of UV reflection from metal surfaces due to multiple factors

3.2.1 Preliminary measurements

The following investigative measurements were carried out on 15 June, 2007 (winter) using the EPP2000.

3.2.1.1 Distance

In order to be able to establish the most effective means of measuring reflectivity from a vertical surface, a number of tests were carried out, including determining if the position of the sensor in relation to the shape of surface affected measurements, and the same for the distance of the sensor from the surface. The trapezoidal profile surfaces have prominent ridges within the structure of the sheeting to increase its strength (dimensions reported in the Methodology). Sensor placement over a ridge or a flat section was investigated at a variety of distances using the zinc aluminium coated trapezoidal sheeting. UV irradiance measurements over these two positions relative to each other at each measurement with 240 data values (from 0.5 nm steps from 280 nm to 400 nm) are shown in Figure 3.1. There is little comparative difference between the two reflected UV irradiance measurements as shown by the linear regression line. The measurements were taken within two minutes of each other in mid-afternoon at SZA of 63.9° and 64.2°. In Figure 3.2, distance from the centre of the surface of the sheeting to the sensor was varied to determine if reflection would vary significantly due to distance. The reflected spectral irradiance measured from 10 cm to 50 cm, was an average of 19% less (per 0.5 nm wavelength step) intensity measured at 50 cm than at 10 cm distance from the metal sheeting. This resulted in a 26% difference (per 0.5 nm wavelength step) in reflective capability. Further distance measurements were explored at 1.0 m from the metal

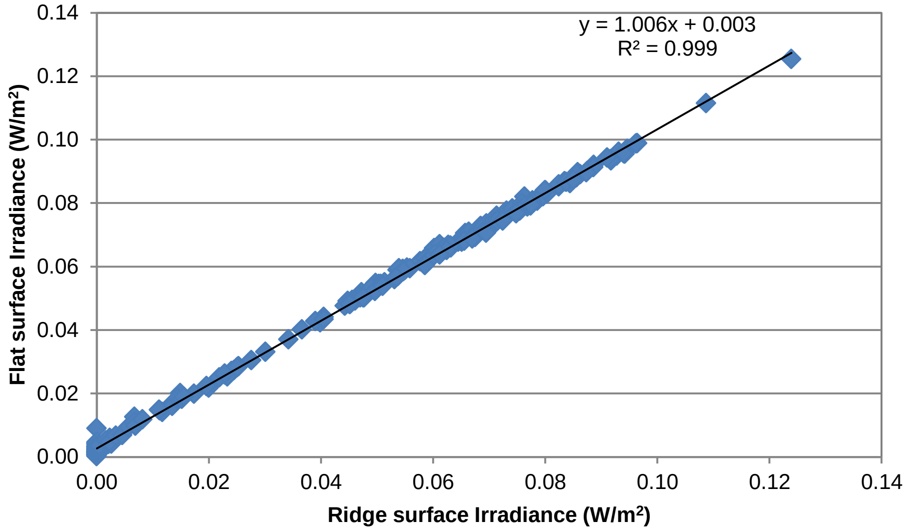

Figure 3.1 - Reflected UV irradiance over a ridge compared to reflected UV irradiance over a flat surface.

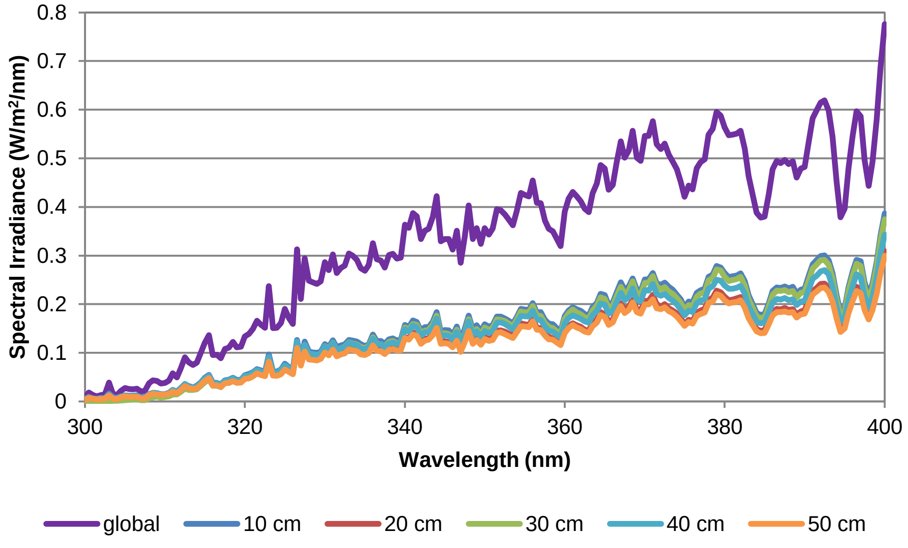

Figure 3.2 – UV irradiance measured from centre of trapezoidal surface at varying distances.

sheeting and compared to 0.5 m distance from the metal sheeting. Figure 3.3 shows global spectral UV irradiance and the reflected spectral UV irradiance at 0.5 m and 1.0 m at 59.1° to 59.7° on the same day as the previous measurements. The intensity measured at 1.0 m is 33% lower than at 0.5 m (average per 0.5 nm wavelength step). This resulted in a difference in reflection intensity of also 33% (Figure 3.4). Significant levels of noise are also visible in Figure 3.4 from 300 nm to 310 nm which were not immediately apparent in Figure 3.3. All figures are shown with the range of 300 nm to 400 nm due to the effect of stray light which occurs in diode array measurement systems, which increases the signal-to-noise measured at shorter wavelengths.

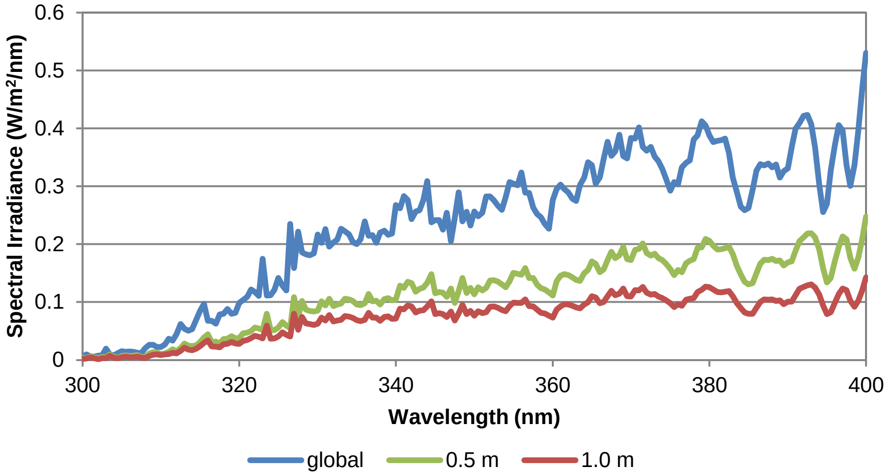

Figure 3.3 - Global and reflected spectral UV irradiance measured at 0.5 m and 1.0 m for vertical north facing zinc aluminium trapezoidal surface.

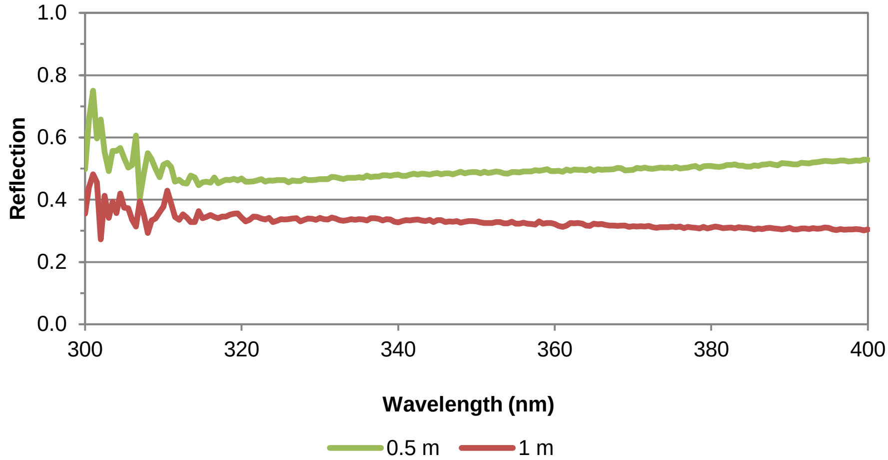

Figure 3.4 - Reflection per wavelength at 0.5 m and 1.0 m sensor distance for vertical north facing zinc aluminium trapezoidal surface.

3.2.1.2 Orientation

Figures 3.5 and 3.6 show the reflected spectral UV irradiance measured from vertical surfaces facing the compass points (north, west, south and east), at two distances 0.5 m (Figure 3.5) and 1.0 m (Figure 3.6) between 56.5° SZA, 29.5° SAA and 59.7° SZA, 35.4° SAA in the morning.

Figures 3.7 and 3.8 display the ratio of the reflected spectral UV irradiance to the measured global spectral UV irradiance taken at the same time. Figure 3.8 identifies an issue with the data obtained from the south facing vertical wall. The sheets are approximately 1 m^2 in area, and at a distance of 1.0 m, the sensor used to measure the south wall reflection is recording higher intensities reflected than incident on the surface, but this does not occur with the sensor at 0.5 m. What is more likely to be occurring is that due to the position of the sun in the sky, direct UV irradiance is incident on the sensor (rather than being reflected), as well as the already reflected UV irradiance and producing a compromised ratio.

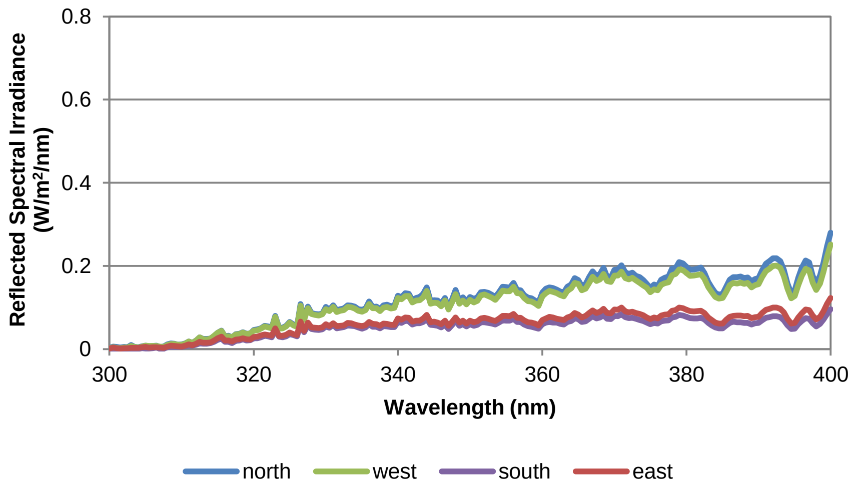

Figure 3.5 – Reflected spectral UV irradiance measured from vertical surface facing the compass points at 0.5 m.

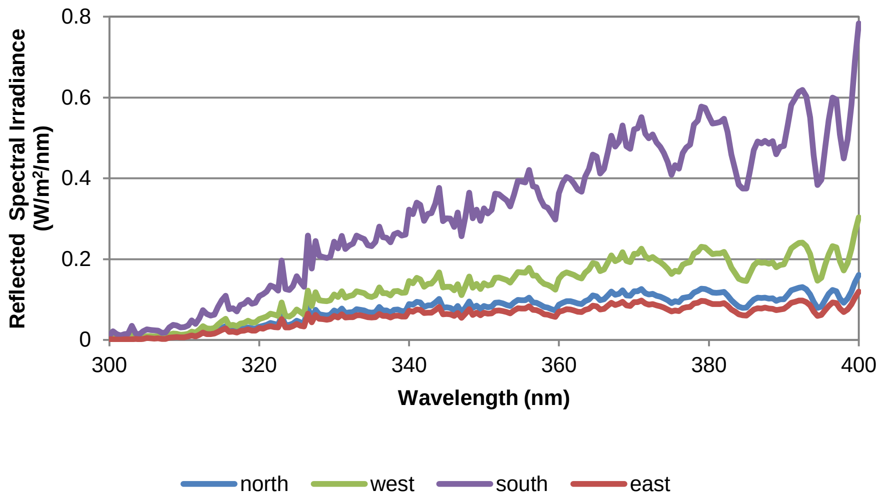

Figure 3.6 - Reflected spectral UV irradiance measured from vertical surface facing compass points at 1.0 m.

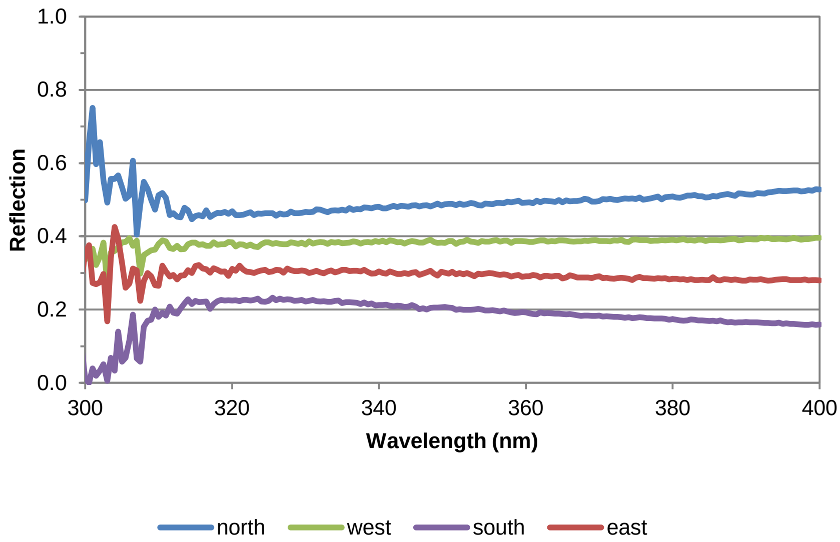

Figure 3.7 - Reflection (ratio compared to global irradiance) measured from vertical surfaces facing compass points at 0.5 m.

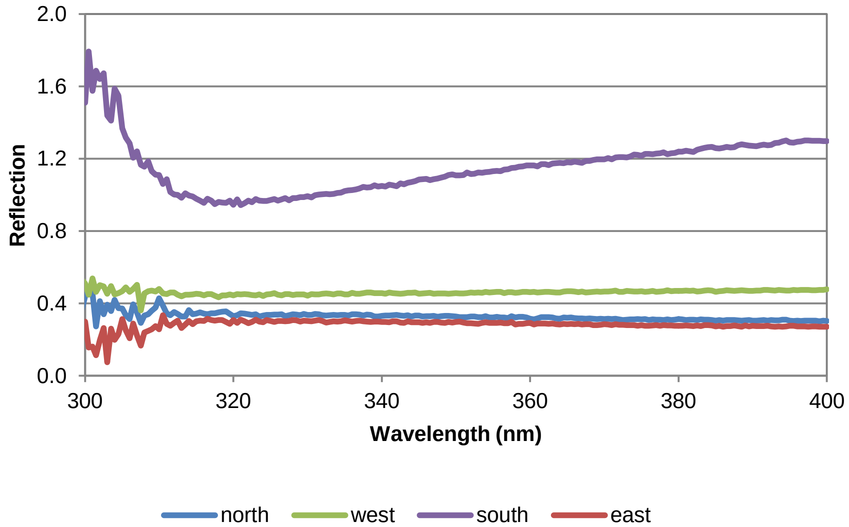

Figure 3.8 - Reflection measured from vertical surfaces facing compass points at 1.0 m.

This is supported by the reflection obtained for the south facing wall measured at 0.5 m (Figure 3.7) which shows the lowest reflection measured for that group of measurements. It is therefore logical to assume that during the day as the sun moves through the sky, the direction of the walls will produce this possibility of measuring additional direct UV irradiance with reflected UV irradiance as observed in Figure 3.6 and significantly alter the reflective ratio.

Reflection measurements from horizontal surfaces have been carried out on a variety of surfaces but reflection measurements from vertical surfaces have been rarely carried out. Figure 3.9 shows the reflected spectral irradiance measured from a vertical surface and a horizontal surface at the same time of day. The resulting reflection ratio is shown in Figure 3.10, which shows a significant difference between the reflective capacities of surfaces that are oriented 90° to each other. It should be again noted that the position of the sun in the sky may change the reflective capacity of the surface, particularly as these measurements were made at fairly large SZA during mid morning in winter.

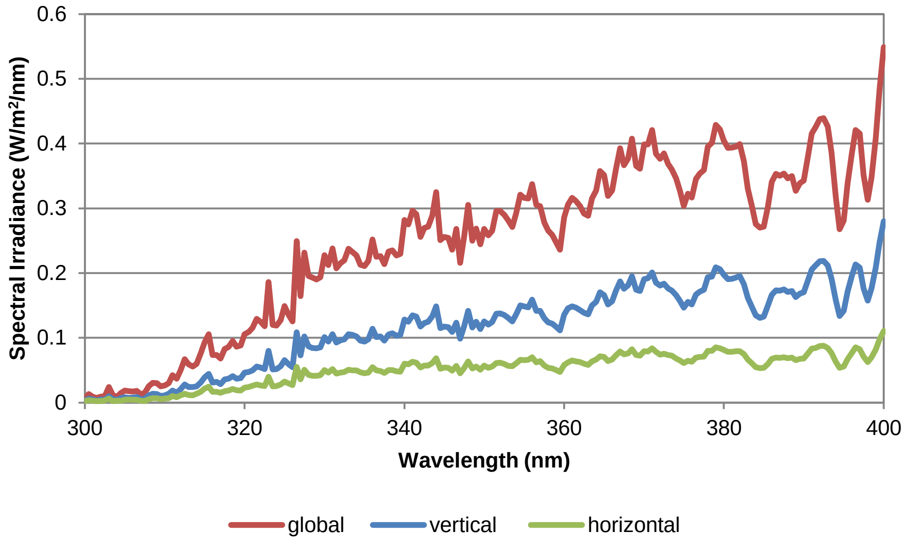

Figure 3.9 - Measurement of global spectral UV irradiance and reflected UV irradiance from north facing vertical and horizontal surfaces from 58.5° to 59.1°.

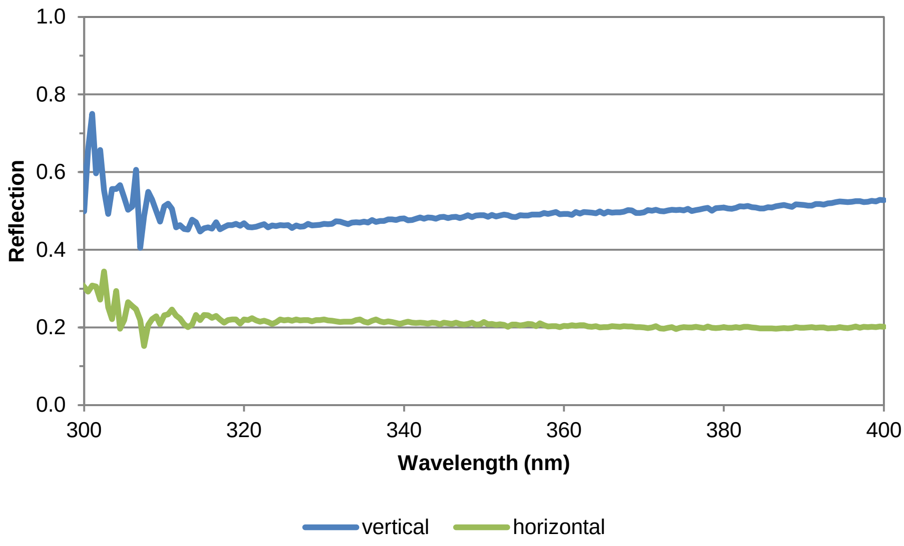

Figure 3.10 - Reflection measured for vertical north facing and horizontal surfaces at 58.5° to 59.1°.

3.2.1.3 Time of day and position of sun in sky

Measurements of vertical reflection were made using zinc aluminium coated trapezoidal sheeting on 30 July, 2007 throughout the day. Figure 3.11 shows the changing reflection per wavelength at different SZA and SAA. These measurements corresponded to times of approximately 8 am, 10 am, noon and 2 pm. The most significantly different reflection measurement is that made at 8 am, which at some of the shortest wavelengths exceeds unity.

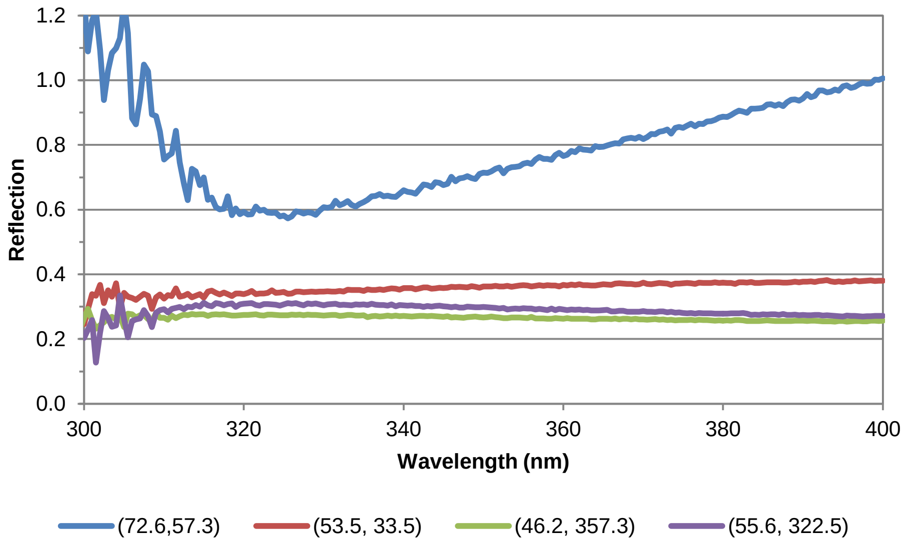

Figure 3.11 - Reflection from north facing vertical zinc aluminium trapezoidal for the SZA and SAA listed.

The reflection ratio then drops to 0.6 at approximately 320 nm, then continues to increase again throughout the UVA waveband. The other three reflection measurements made around the middle of the day, whilst not the same intensity in reflection are more consistent across the UV spectrum. In comparison, the reflection from a horizontal surface in Figure 3.12 does not show as much difference in measurements between early morning and later times and instead shows a fairly consistent reflection across the UV spectrum despite changing SZA and SAA. There is however some fluctuation occurring from 300 nm to 310 nm in the early morning measurement.

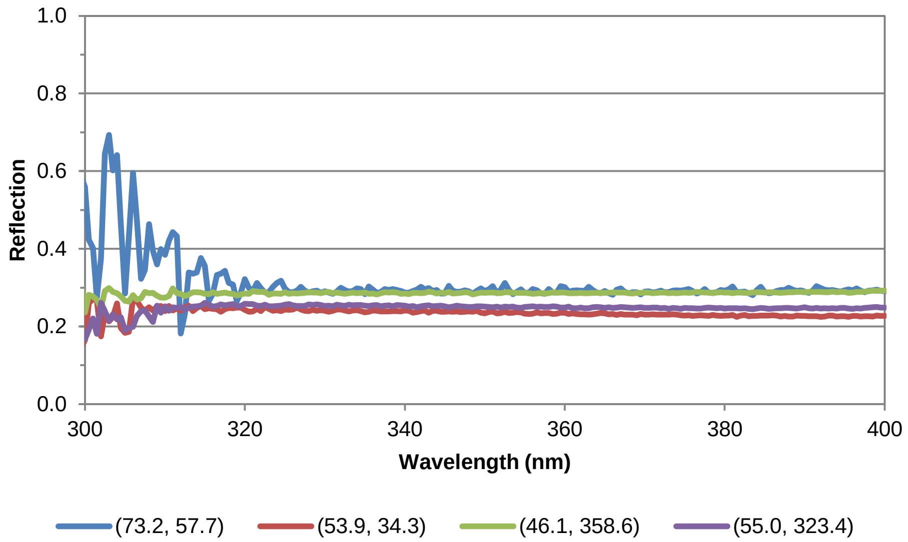

Figure 3.12 - Reflection from horizontal zinc aluminium trapezoidal for the SZA and SAA listed.

3.2.2 Investigative measurements of different surface types

A variety of metal surface types that may be used for vertical, inclined or horizontal surfaces in urban construction were investigated. Each surface type was investigated for reflection from vertical, inclined and horizontal surfaces, for different orientations and time of day. Measurements were carried out on clear or reasonably clear days throughout winter in 2007.

3.2.2.1 Zinc aluminium trapezoidal

Measurements for this surface type were carried out on 30 July, 2007. Figures 3.11 and 3.12 are also examples of some of the data collected from this surface type. Figures 3.13 and 3.14 display variation in reflectivity due to changes in orientation, SZA and SAA for vertical north facing and horizontal surfaces respectively.

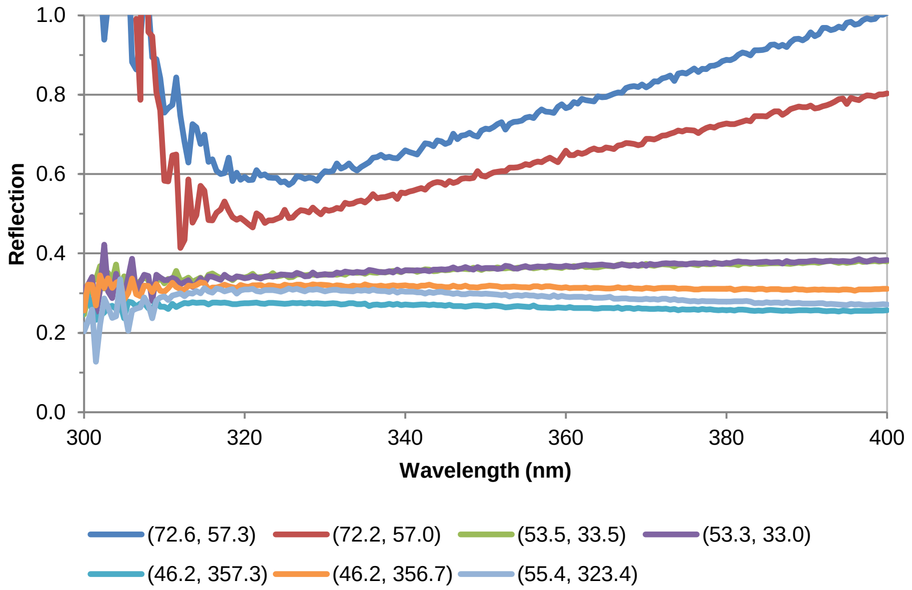

Figure 3.13 - Reflection from north facing zinc aluminium trapezoidal vertical surface for the SZA and SAA listed.

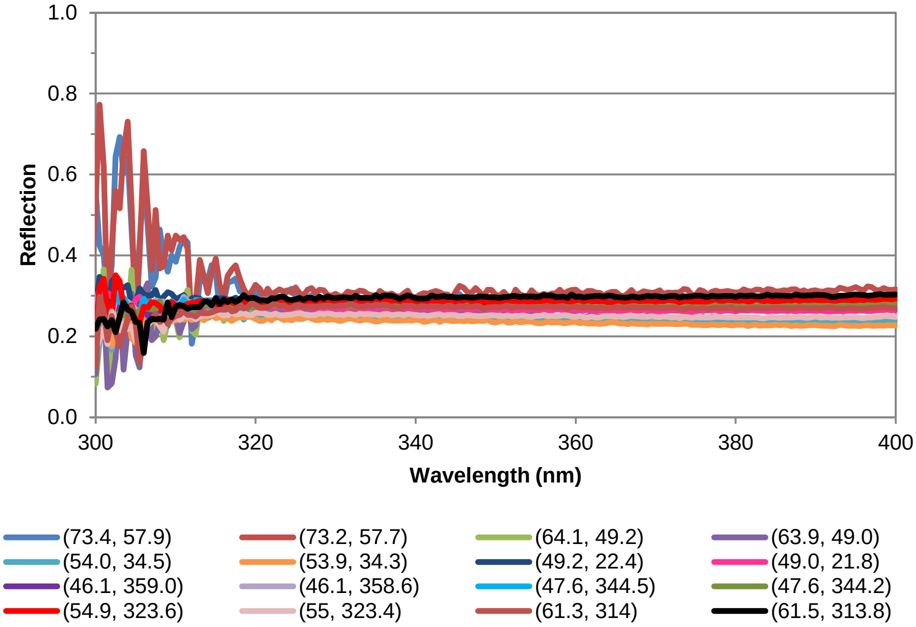

Figure 3.14 - Reflection from a horizontal zinc aluminium trapezoidal surface at various SZA and SAA.

For Figure 3.14, this data has been averaged and the highest and lowest possible reflection magnitudes have been presented in Figure 3.15. Figure 3.16 presents the variation in reflectivity on north facing inclined surfaces. To compare all this data Figure 3.17 has averaged distinct reflectivity measurements. Due to the significant variation between very large SZA in early morning measurements and the later mid morning to mid afternoon measurements, these have been averaged per wavelength separately.

Figures 3.7 and 3.8 show the variation in reflectivity due to the orientation of the vertical surfaces towards the compass points at similar points of time in the day. Like the variation displayed by the north facing surface in Figures 3.13 and 3.16, so too do the east, west and south vertical and inclined surfaces have varying reflectivity due to varying SZA and SAA. Except for times of day when the sun shines directly on a surface, the remaining compass points of east, south and west, may have lower reflectivity, since the sun remains either north of east or north of west throughout the day in the southern hemisphere. Figures 3.18 to 3.20 show the average reflectivity per wavelength for different orientations and time of day. From these charts it is clear that surfaces oriented towards the sun, have the highest average reflectivity. For vertical or inclined surfaces facing away from the normal to the sun, there is lower average reflectivity per wavelength observed.

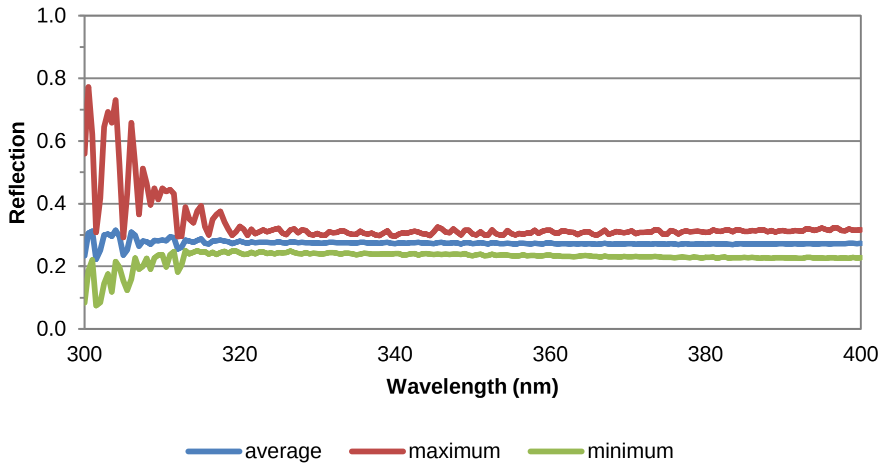

Figure 3.15 - Variation in horizontal reflection with changing SZA and SAA per wavelength (range from 73.4, 57.9 early morning to 46.1, 359 midday to 61.3, 314 mid afternoon). Averaged from Figure 3.14.

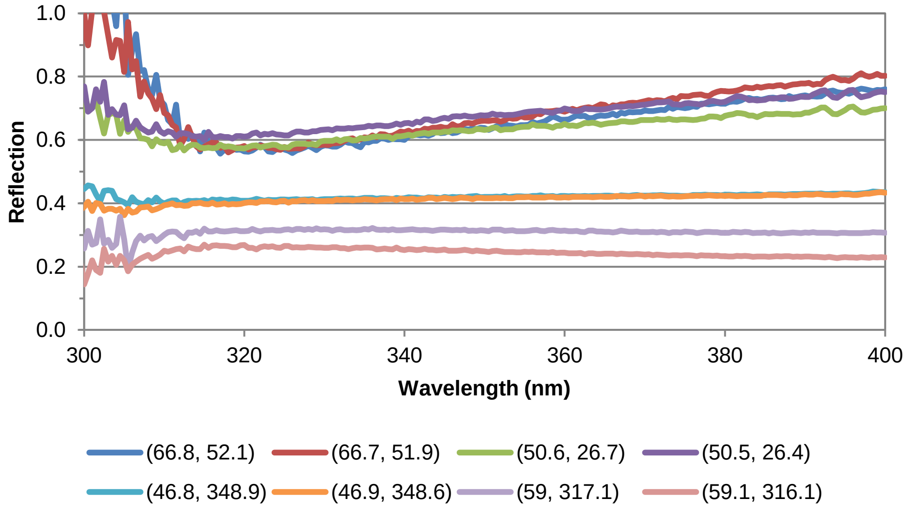

Figure 3.16 - Reflection from inclined north facing zinc aluminium trapezoidal at various SZA and SAA.

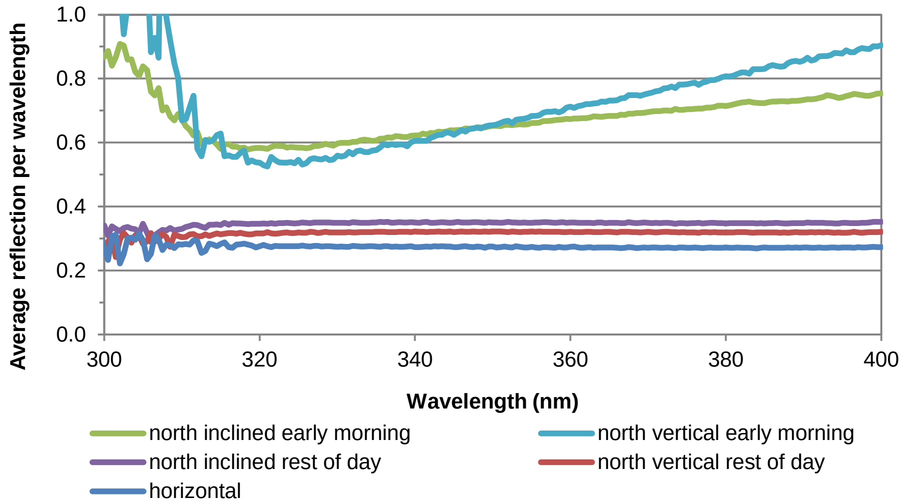

Figure 3.17 - Average reflection per wavelength north facing for inclined and vertical for various SZA and SAA.

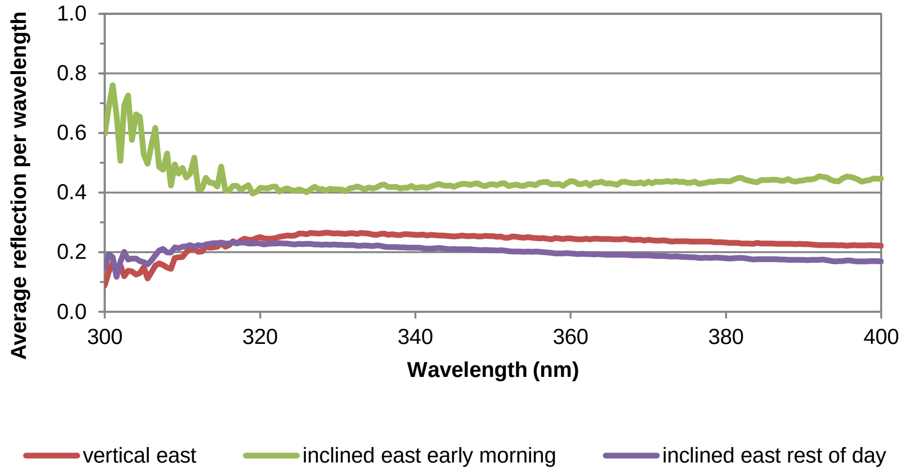

Figure 3.18 - Average reflection per wavelength for east facing inclined and vertical surfaces.

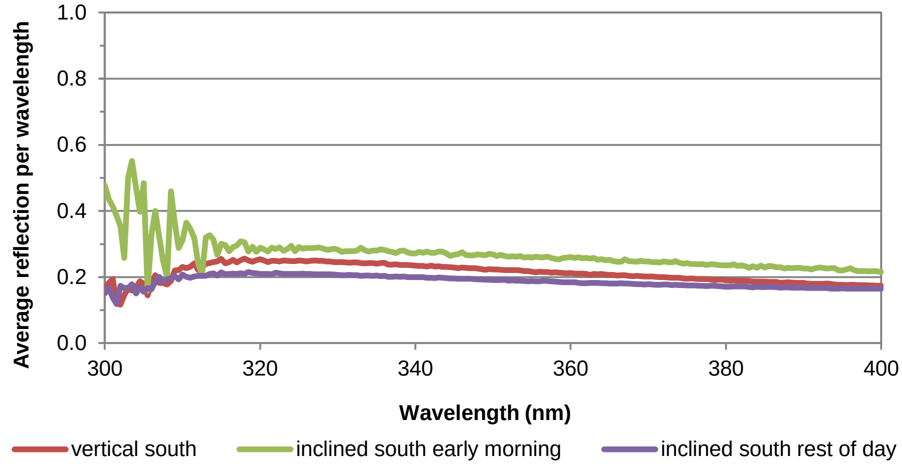

Figure 3.19 - Average reflection per wavelength for south facing vertical and inclined surfaces.

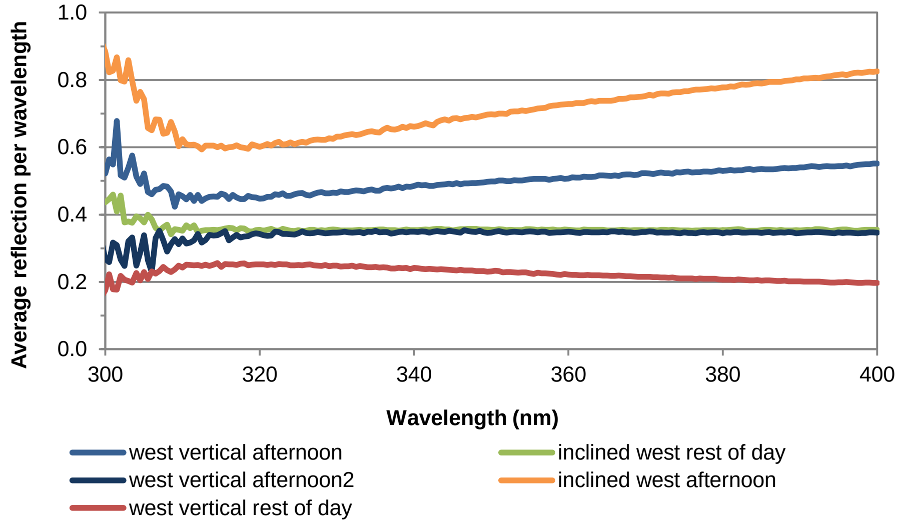

Figure 3.20 - Average reflection per wavelength for west facing vertical and inclined surfaces.

3.2.2.2 All other surface types measured

Due to the large quantity of data obtained, the remaining graphs displaying the appropriate spectral reflection from all surface types investigated can be found in Appendix 7.1. The data from these graphs has been collated into tables in order to be able to compare the reflective capability of the surface types investigated. To compare, the reflection at 320 nm has been selected, as this appears to be where either minimum reflection occurs (for non-coated metal surfaces) or maximum reflection occurs (for most coated metal surfaces). The data are presented in Tables 3.1 and 3.2.

Table 3.1 - Average reflection for five surface types at different orientation, and time of day, taken at 320 nm in the spectral range due to maximum or minimum reflection occurring at this wavelength.

	Average reflection at 320 nm				
Metal Type	Zinc Aluminium Trapezoidal	Zinc Aluminium Corrugated	Beige Trapezoidal	Cream Trapezoidal	Cream Corrugated
Horizontal	0.28	0.28	0.05	0.06	0.06
North vertical					
Early morning	0.54	0.34	0.21	0.24	0.32
Mid morning	0.34	0.32	0.13	0.15	0.12
Midday	0.30	0.27	0.10	0.13	0.11
Afternoon	0.31	0.32	0.15	0.17	0.14
North inclined					
Early morning	0.57	0.52	0.14	0.19	0.14
Mid morning	0.59	0.45	0.14	0.11	0.09
Midday	0.41	0.41	0.06	0.08	0.10
Afternoon	0.29	0.38	0.07	0.09	0.11
West vertical					
Early morning	-	-	-	-	-
Mid morning	0.25	0.22	0.13	0.14	0.12
Midday	0.26	0.28	0.10	0.13	0.12
Afternoon	0.40	0.39	0.15	0.18	0.15
West inclined					
Early morning	0.36	0.27	0.06	0.08	0.06
Mid morning	0.32	0.36	0.05	0.08	0.08
Midday	0.36	0.40	0.08	0.08	0.08
Afternoon	0.60	0.46	0.12	0.13	0.12
South vertical					
Early morning	0.28	0.32	0.19	0.24	0.23
Mid morning	0.22	0.24	0.15	0.18	-
Midday	-	-	-	-	-
Afternoon	0.25	0.38	0.16	0.30	0.19
South inclined					
Early morning	0.29	0.33	0.05	0.08	-
Mid morning	-	0.18	0.03	0.05	0.05
Midday	0.19	0.18	0.05	0.04	0.05
Afternoon	0.22	0.26	0.07	0.05	0.08
East vertical					
Early morning	0.22	0.35	0.18	0.20	0.19
Mid morning	0.21	0.23	0.14	0.13	0.12
Midday	-	-	-	-	-
Afternoon	0.32	0.29	0.17	0.21	0.17
East inclined					
Early morning	0.41	-	-	0.12	0.09
Mid morning	0.26	0.37	0.05	0.06	0.06
Midday	0.24	0.21	0.06	0.06	0.06
Afternoon	0.21	0.22	0.06	0.05	0.05

Table 3.2- Average reflection for five surface types at different orientation, and time of day, taken at 320 nm in the spectral range due to maximum or minimum reflection occurring at this wavelength.

	Average reflection at 320 nm				
Metal Type	Medium Blue Trapezoidal	Insultec Coated Trapezoidal	Black Trapezoidal	Dark Red Trapezoidal	Pale Green Corrugated
Horizontal	0.05	0.06	0.03	0.03	0.04
North vertical					
Early morning	0.20	0.23	0.20	0.23	0.20
Mid morning	0.11	0.13	0.12	0.11	0.11
Midday	0.09	0.12	0.10	0.11	0.12
Afternoon	0.18	0.13	0.13	0.14	0.13
North inclined					
Early morning	0.08	0.16	0.16	0.08	0.10
Mid morning	0.08	0.12	0.12	0.07	0.08
Midday	0.05	0.10	0.10	0.07	-
Afternoon	-	0.08	0.08	0.06	0.06
West vertical					
Early morning	-	-	-	-	-
Mid morning	0.13	0.14	0.14	0.18	0.13
Midday	0.11	0.11	0.11	0.11	0.11
Afternoon	0.16	0.17	0.17	0.14	0.14
West inclined					
Early morning	0.06	0.08	0.08	0.07	0.06
Mid morning	0.04	0.07	0.07	0.03	-
Midday	0.08	0.08	0.08	0.07	0.06
Afternoon	-	0.14	0.14	-	0.10
South vertical					
Early morning	-	0.22	0.22	-	-
Mid morning	0.73*	0.73*	0.21*	0.16*	-
Midday	0.43*	0.45*	0.41*	0.40*	0.45*
Afternoon	-	0.24	0.22	0.18	0.20
South inclined					
Early morning	0.04	0.11	0.06	0.04	0.05
Mid morning	0.03	0.05	0.03	0.03	0.03
Midday	0.04	0.05	0.02	0.05	0.03
Afternoon	0.05	0.05	0.03	0.05	0.08
East vertical					
Early morning	0.15	0.21	0.17	0.17	0.18
Mid morning	0.10	0.12	0.11	0.12	0.39*
Midday	0.30*	0.42*	0.35*	0.38*	-
Afternoon	-	0.15	-	-	0.18
East inclined					
Early morning	0.07	0.11	0.05	0.07	0.08
Mid morning	0.05	0.07	0.05	0.04	0.07
Midday	0.03	0.06	0.03	0.06	0.04
Afternoon	-	0.06	0.03	0.04	0.07

* Data suspected of direct irradiance from sun thus potentially raising reflection value

3.2.3 Repeated experiments

The technique of measuring reflection was modified and improved after the preliminary measurements were made. To ensure all direct UV irradiance from the sun is incorporated into the reflection measurement, the reflection ratio was calculated from reflected UV irradiance relative to UV irradiance measured with the sensor oriented towards the position of the sun in the sky (total UV irradiance). Previous measurements calculating reflection from global UV irradiance (with the sensor horizontally positioned facing the hemisphere of the sky) was shown to not account for all UV irradiance as the sun changes position in the sky during the day. A comparison of the spectral reflection from global and total UV irradiances are presented in Figures 3.21 and 3.22 respectively.

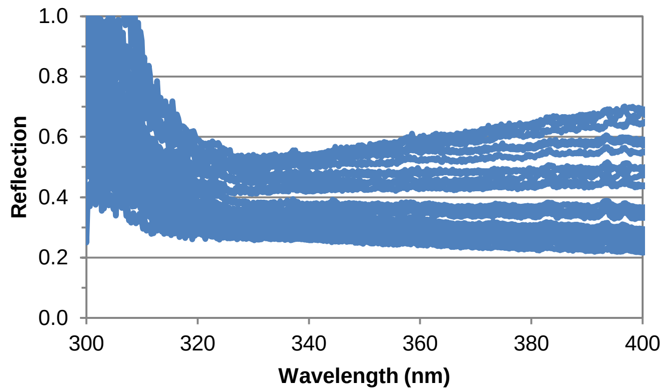

Figure 3.21 – Multiple spectral reflection measurements with respect to global measured UV irradiance taken over several hours in Autumn 2008.

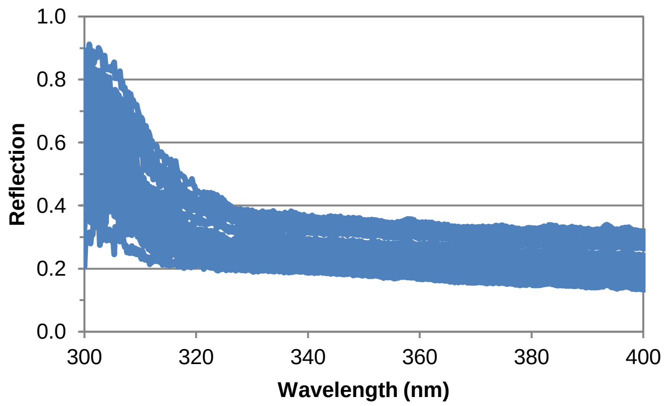

Figure 3.22 – Multiple spectral reflection measurements with respect to total measured UV irradiance taken over several hours in Autumn 2008.

3.2.3.1 Zinc aluminium trapezoidal

The repeated spectral measurements for all metal surface types were carried out in the latter half of 2010, in winter (August) and spring (October). Figures 3.23, 3.24 and 3.25 display the data collected in winter for vertical, horizontal and inclined north facing surfaces respectively. In order to compare the data to spring, averages were calculated and plotted in Figure 3.26.

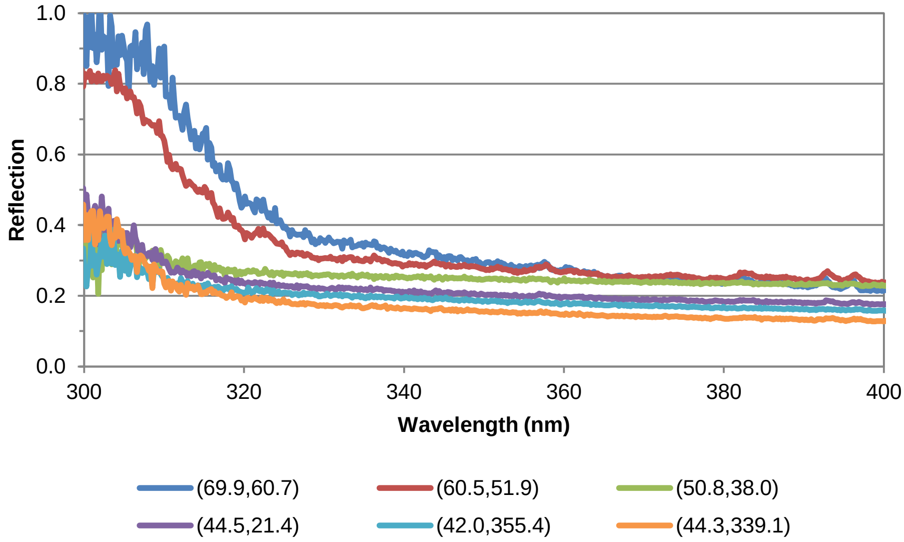

Figure 3.23 - Reflection from zinc aluminium trapezoidal vertical north facing surfaces for varying SZA and SAA in Winter 2010.

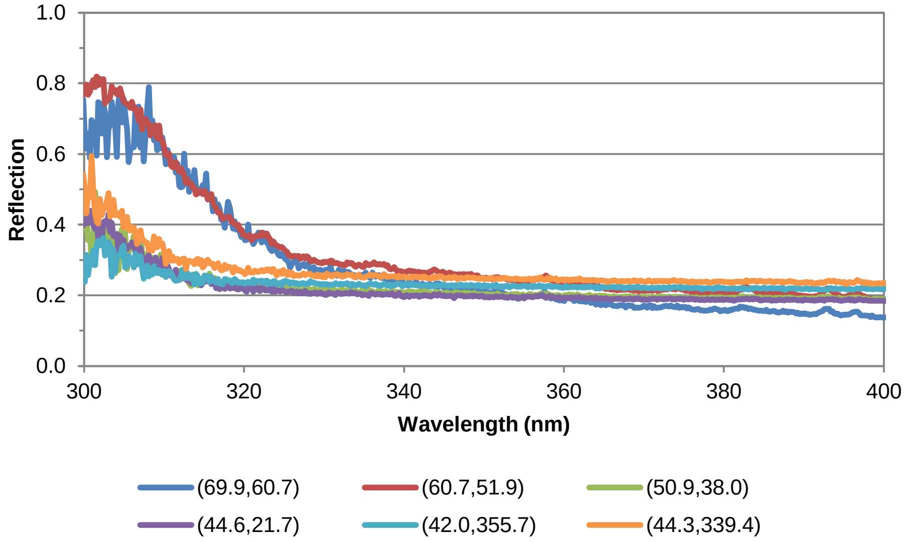

Figure 3.24 - Reflection from zinc aluminium trapezoidal horizontal surface for varying SZA and SAA in Winter 2010.

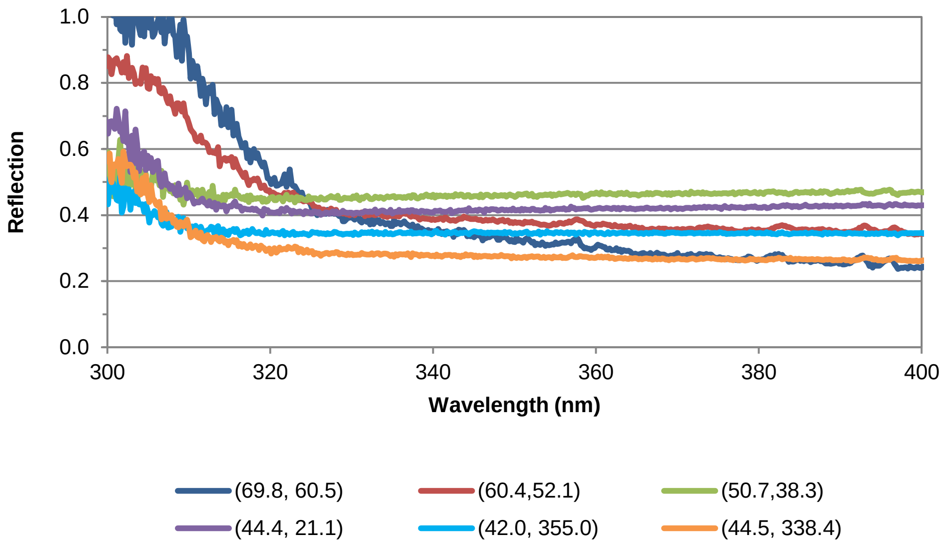

Figure 3.25 - Reflection from zinc aluminium trapezoidal north inclined surface for varying SZA and SAA (Winter 2010).

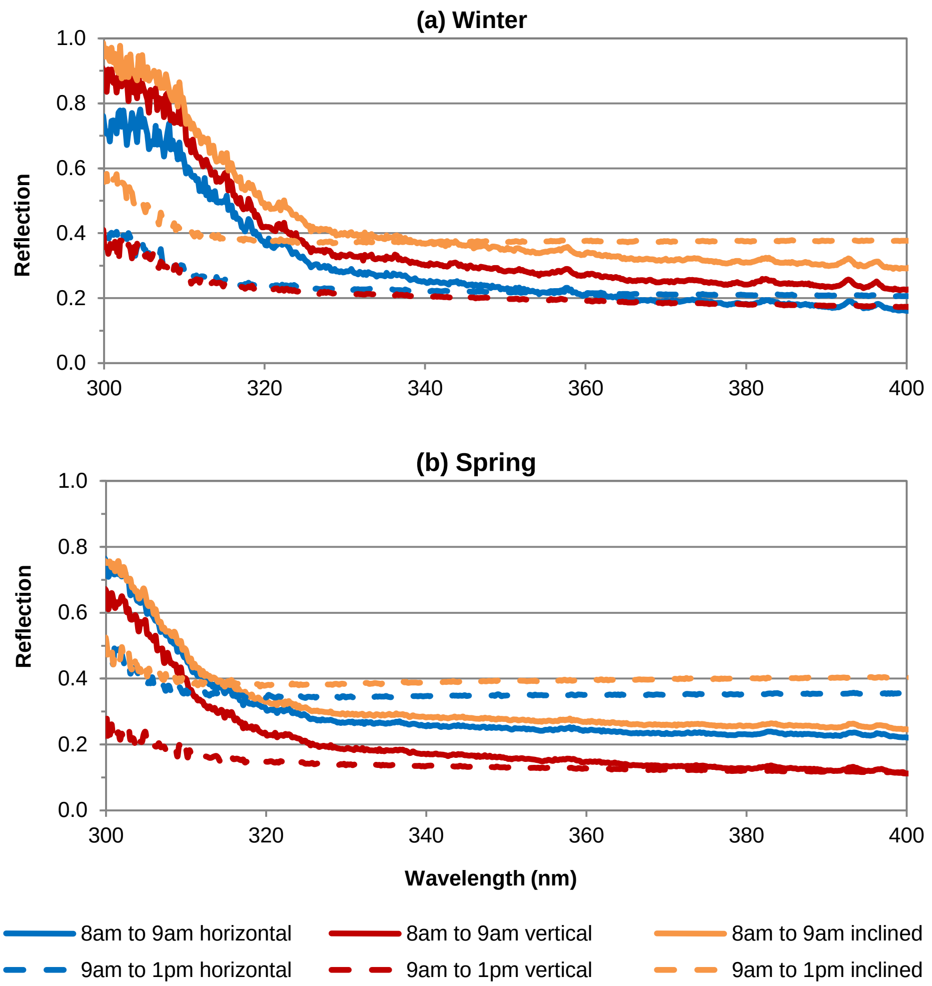

Figure 3.26 - Average reflection for zinc aluminium trapezoidal for horizontal and north facing vertical and inclined surfaces for varying SZA and SAA in (a) Winter 2010 and (b) Spring 2010.

From the data presented in the previous charts, the minimum, maximum and average spectral reflection has been calculated and presented in Figure 3.27, which is a clearer presentation of the spread and range of the spectral data obtained. Comparing spectral reflection was achieved by plotting the average spectral reflection from each session from all measurements made for this surface type over the course of the study, in Figure 3.28. Two distinct spectral reflection averages are immediately noticeable, and can be grouped according to season of the measurement, autumn and spring. This figure only displays the data obtained in the repeated spectral reflection measurements made using the USB4000.

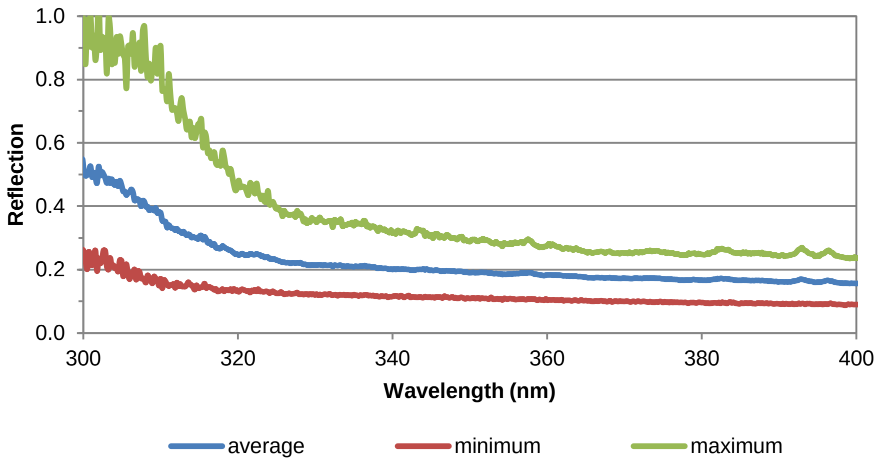

Figure 3.27 – Average, minimum and maximum spectral reflection for vertical zinc aluminium trapezoidal for winter and spring 2010.

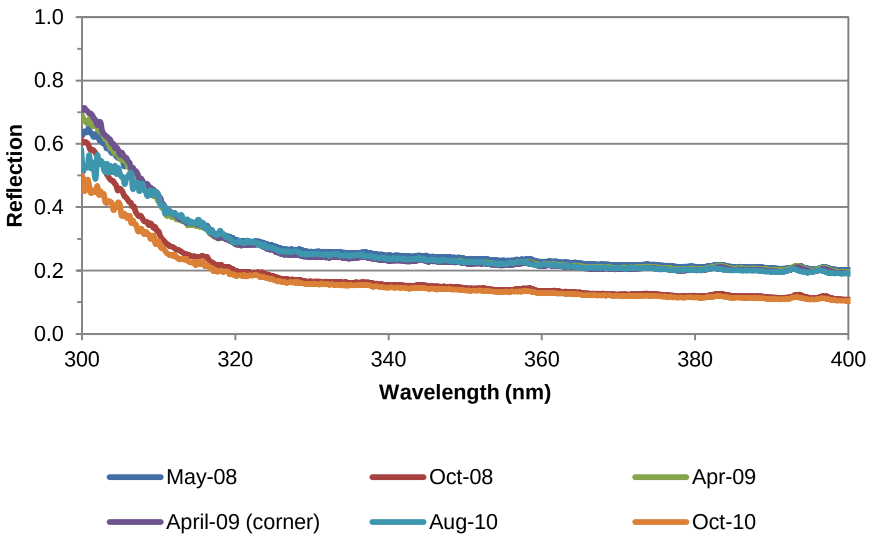

Figure 3.28 – Average daily reflection from zinc aluminium trapezoidal vertical north facing surface for all measurement sessions.

Over the course of the entire study, numerous spectral reflection measurements were made, and particularly for this surface type. Using the methods previously outlined, each spectral reflection measurement was converted to a single erythemally weighted reflection ratio. Figure 3.29 presents this data for this surface type in a vertical position for changing SZA, and a line of best fit has been included with its associated function. From this data, Figure 3.30 displays the average erythemal reflection ratio over SZA groupings with standard deviation. It is apparent here that if a line of best fit was applied, a second order polynomial would express the average ratio change with SZA.

Using this same idea, Figure 3.31 compares this same calculation for all the vertical, horizontal and inclined average erythemal reflection ratios. The number of inclined and horizontal data values was much less than the total number of vertical data values. The bars without standard deviation indicators are those with only one or two measurements for that total SZA group. The average inclined reflection is greater than both vertical and horizontal reflection averages. At smaller SZA it appears horizontal reflections are greater than vertical, although there may not be enough data to be conclusive about this. At greater SZA, the average horizontal and vertical reflection ratios are comparable until the largest SZA, when the average vertical reflection is greater than the average horizontal reflection. Carrying on the data from Figure 3.29, Figure 3.32 shows all the erythemal reflections measured for this surface type for all orientations, structures and positions. Whilst the smaller individual groups of structures and positions do not appear to follow the same trend as the vertical reflection erythemal ratios, altogether, all the data does appear to follow the same trend.

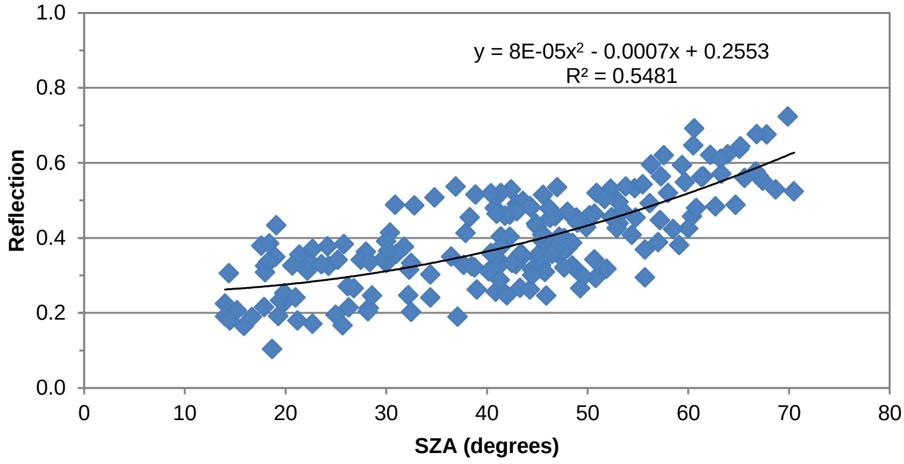

Figure 3.29 - Erythemal weighted reflection from a north facing vertical zinc aluminium trapezoidal surface over a variety of SZA with predicted model of best fit.

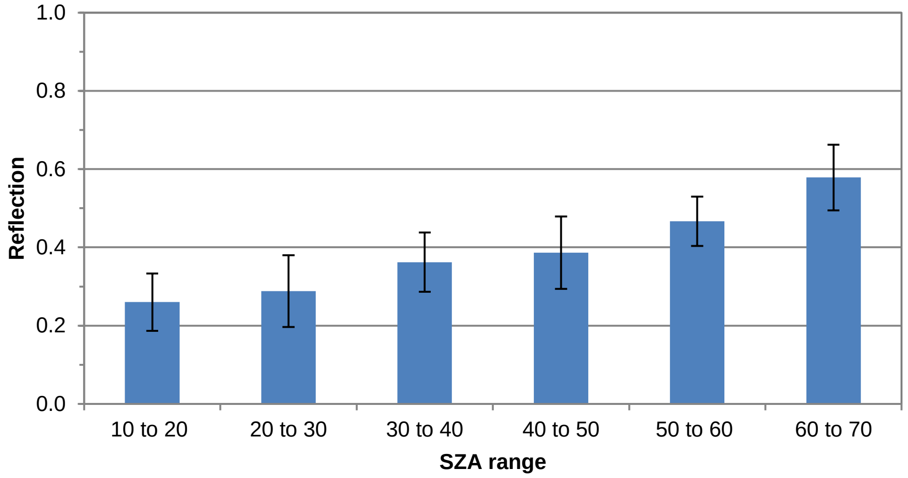

Figure 3.30 - Average ratio of erythemal reflected irradiance to erythemal direct irradiance for different SZA ranges for zinc aluminium trapezoidal (2008 to 2010).

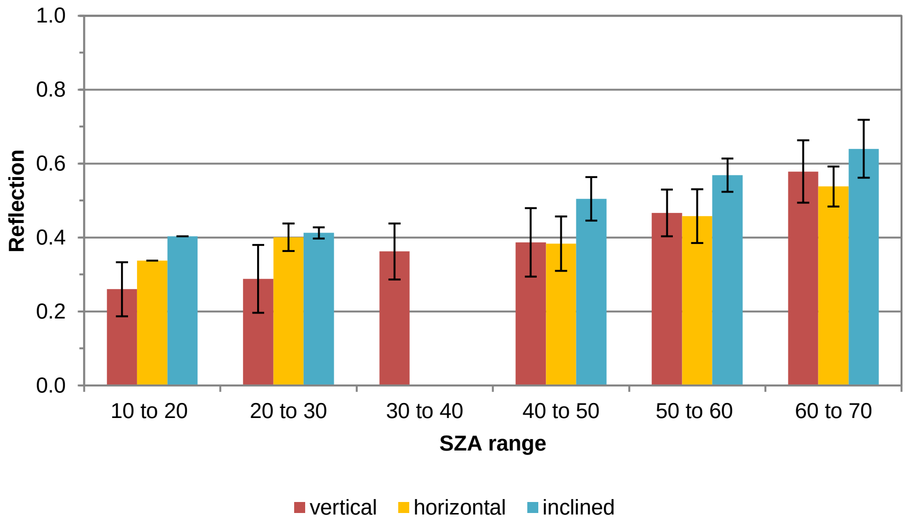

Figure 3.31 - Average ratio of erythemal reflected irradiance to erythemal direct irradiance for vertical, inclined and horizontal zinc aluminium trapezoidal surfaces for varying SZA (2008 to 2010) with standard deviation represented by the error bars.

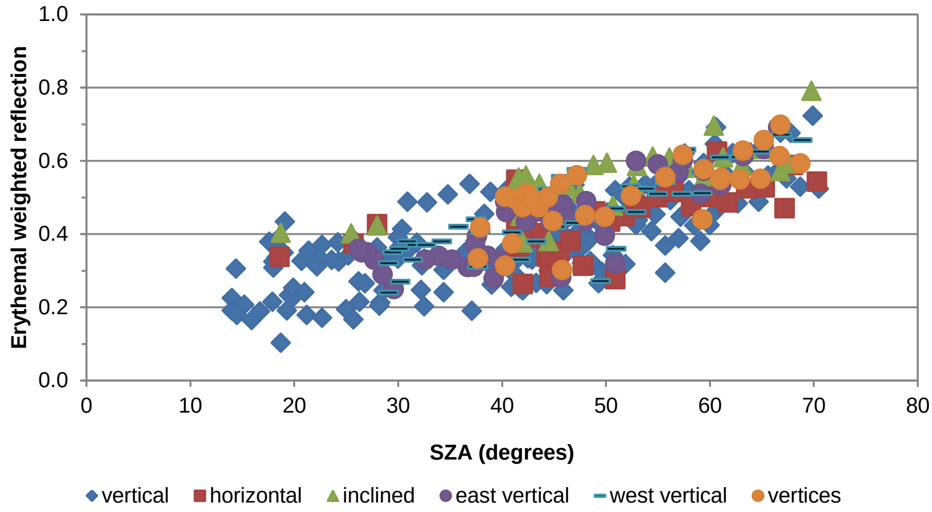

Figure 3.32 – Erythemal weighted reflection for all surface orientations (where direction is not indicated it implies a north aspect).

3.2.3.2 Zinc aluminium corrugated

The analysis carried out for zinc aluminium trapezoidal was repeated for all the surface types explored. The graphs exploring averages are presented, rather than the individual measurements, as it is clear that there are variations in reflection throughout the day and is the case for all metal surfaces explored. However, only those surfaces used in the UV exposure measurements (Section 3.3) had additional spectral measurements taken, and therefore had more data that can be converted to erythemal reflection ratios and analysed for trends. Figure 3.33 shows much less data available for zinc aluminium corrugated. Figure 3.34 displays the minimum, maximum and average spectral reflection ratios for the data collected in 2010 and Figure 3.35 displays the measurement session averages. Figure 3.36 displays the spectral reflection averages for spring and autumn measurements in 2010 for vertical, inclined and horizontal reflections.

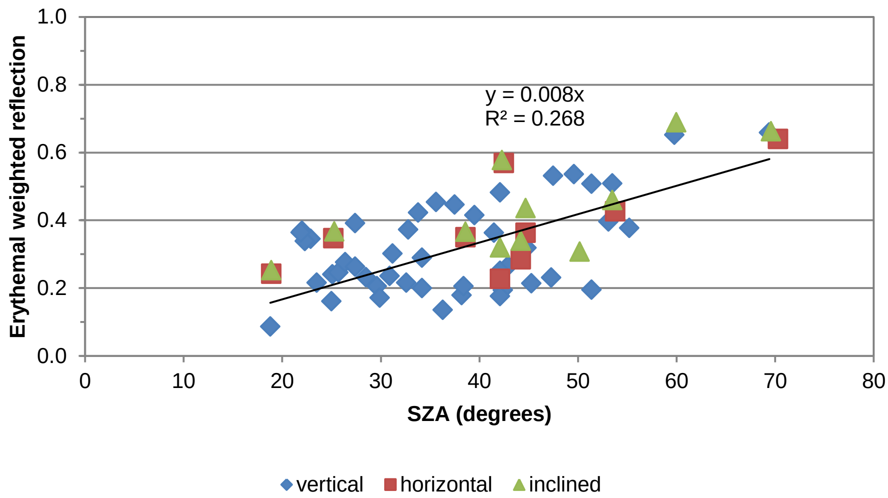

Figure 3.33 - Erythemal weighted reflection from north facing zinc aluminium corrugated surfaces over a variety of SZA with predicted model of best fit for vertical data.

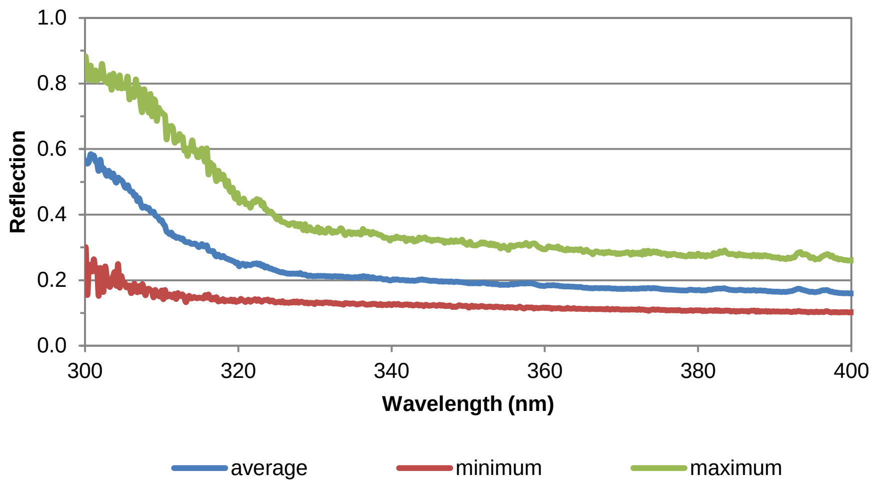

Figure 3.34 – Average, minimum and maximum reflection from a zinc aluminium corrugated vertical surface during Winter and Spring 2010.

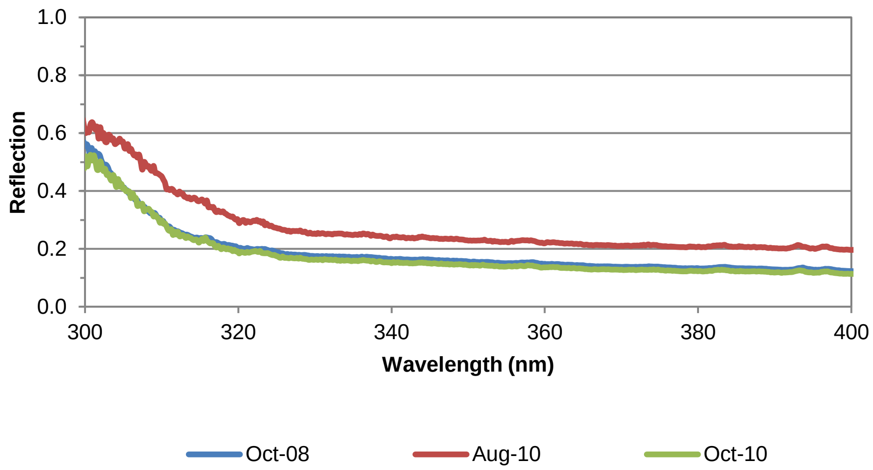

Figure 3.35 – Average daily reflection from zinc aluminium corrugated vertical north facing surface for all measurement sessions.

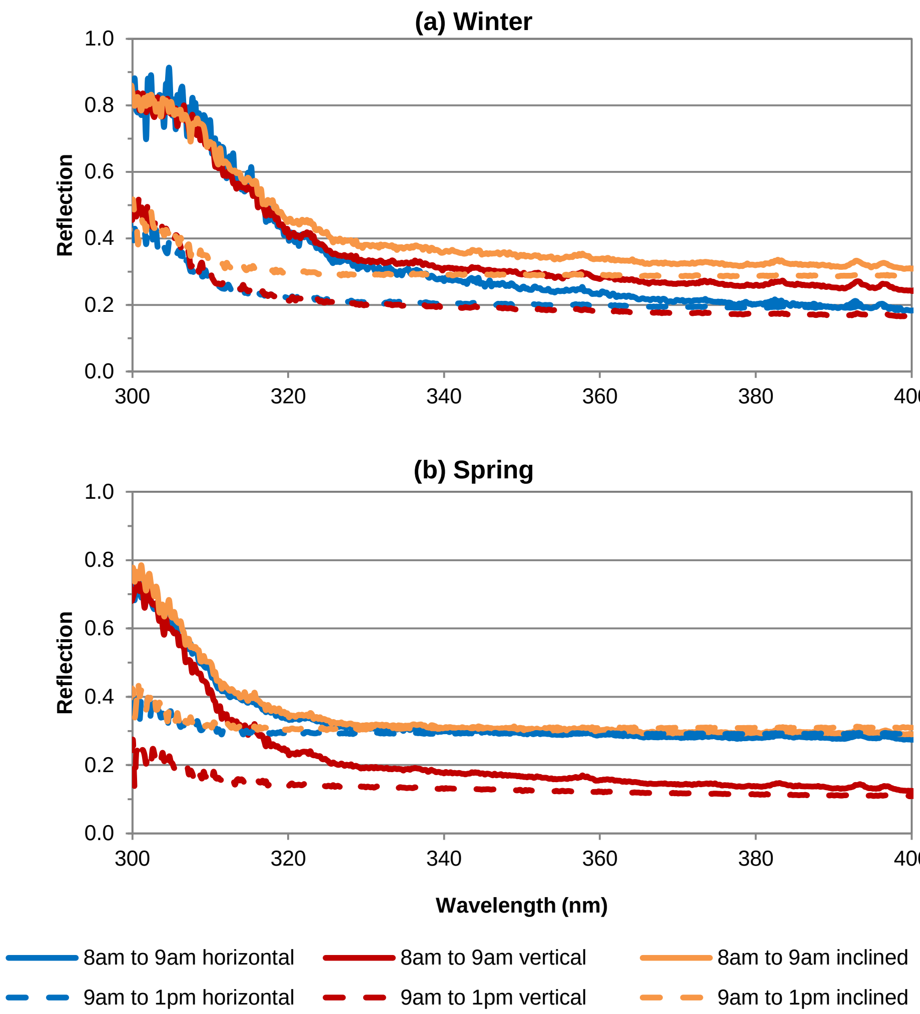

Figure 3.36 - Average reflection for zinc aluminium corrugated for horizontal and north facing vertical and inclined surfaces for varying SZA and SAA in (a) Winter 2010 and (b) Spring 2010.

3.2.3.3 Cream trapezoidal

Figure 3.37 displays the erythemal reflection ratio data with a superimposed line of best fit for the vertical data and corresponding function. Figure 3.38 displays the minimum, maximum and average spectral reflection and Figure 3.39 displays the measurement sessions spectral reflection averages. Figure 3.40 displays the data comparing spring and winter spectral reflections for 2010.

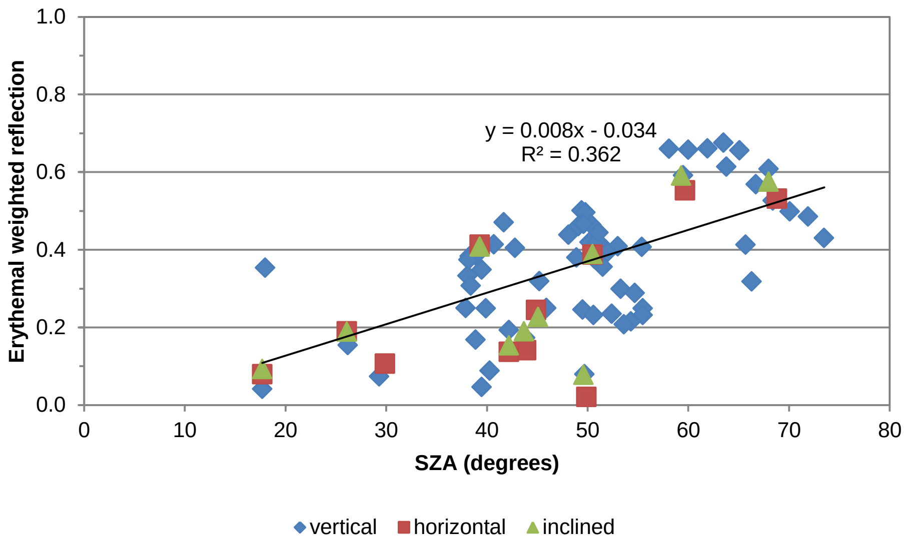

Figure 3.37 - Erythemal weighted reflection from north facing cream trapezoidal surfaces over a variety of SZA with predicted model of best fit for vertical data.

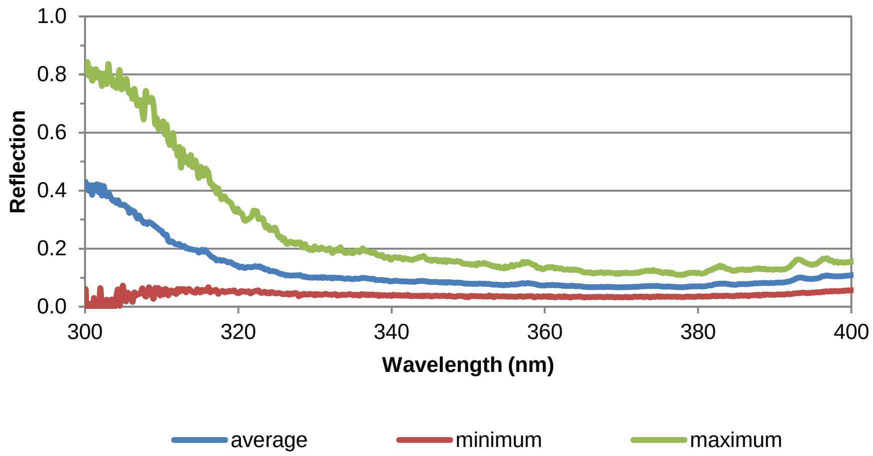

Figure 3.38 - Average, minimum and maximum reflection from a cream trapezoidal vertical surface during Winter and Spring 2010.

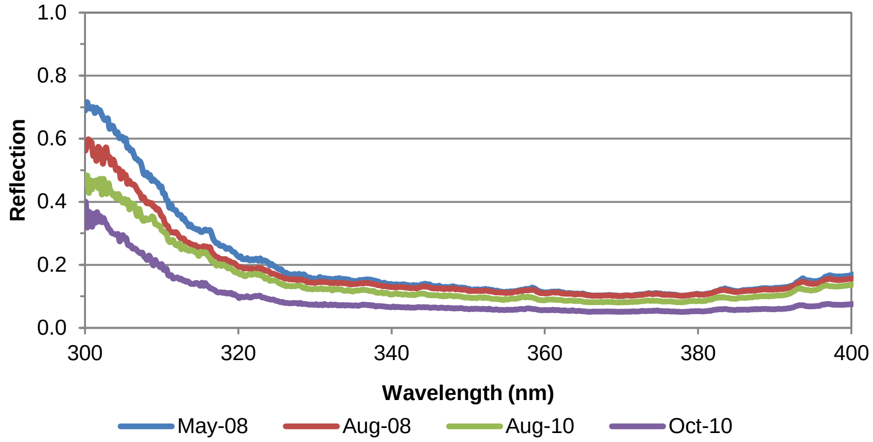

Figure 3.39 – Average daily reflection from cream trapezoidal vertical north facing surface for all measurement sessions.

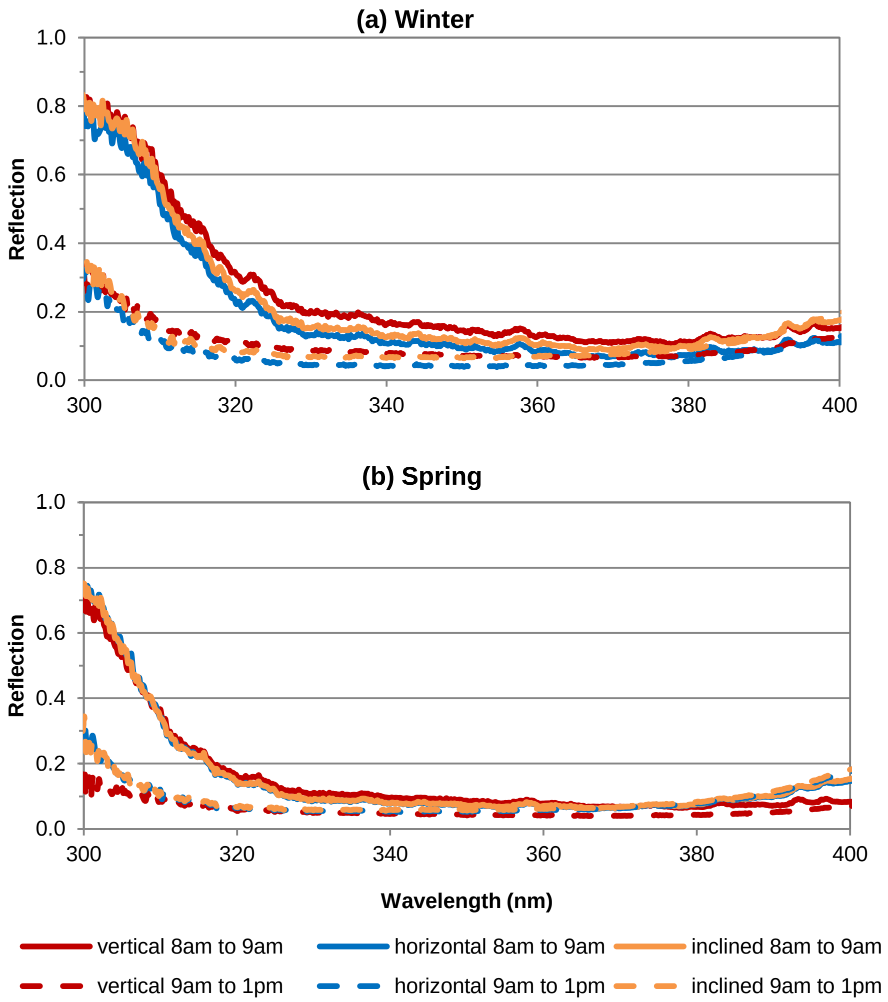

Figure 3.40 - Average reflection for cream trapezoidal for horizontal and north facing vertical and inclined surfaces for varying SZA and SAA in (a) Winter 2010 and (b) Spring 2010.

3.2.3.4 Cream corrugated

Figure 3.41 displays the minimum, maximum and average spectral reflection data for a cream corrugated vertical surface.

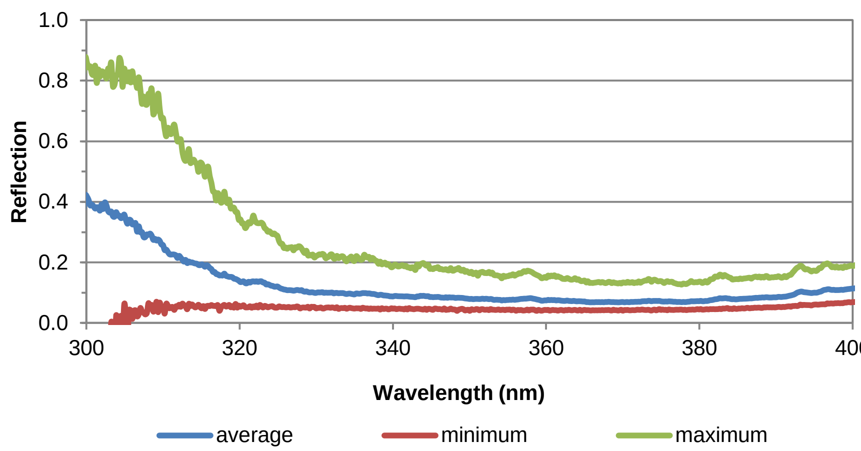

Figure 3.41 - Average, minimum and maximum reflection from a cream corrugated vertical surface during Winter and Spring 2010.

Figure 3.42 displays the measurement session averages and Figure 3.43 displays the comparison between spring and winter in 2010. There was insufficient data to plot the erythemal reflection ratios against SZA.

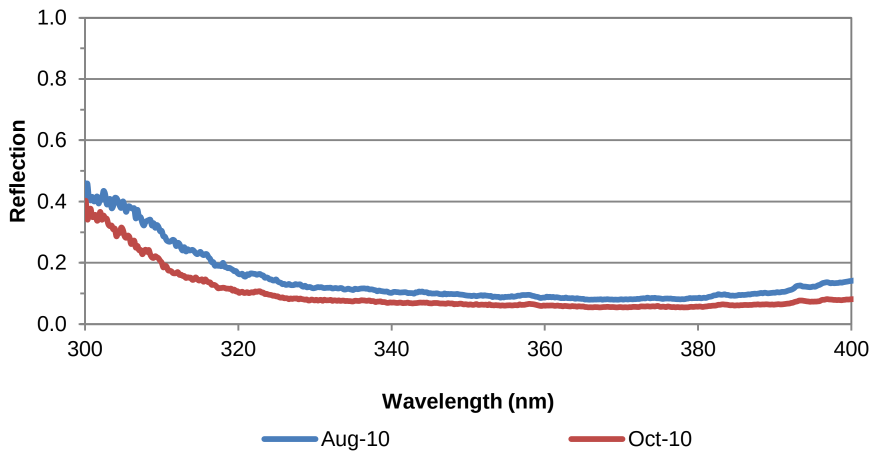

Figure 3.42 – Average daily reflection from cream corrugated vertical north facing surface for all measurement sessions.

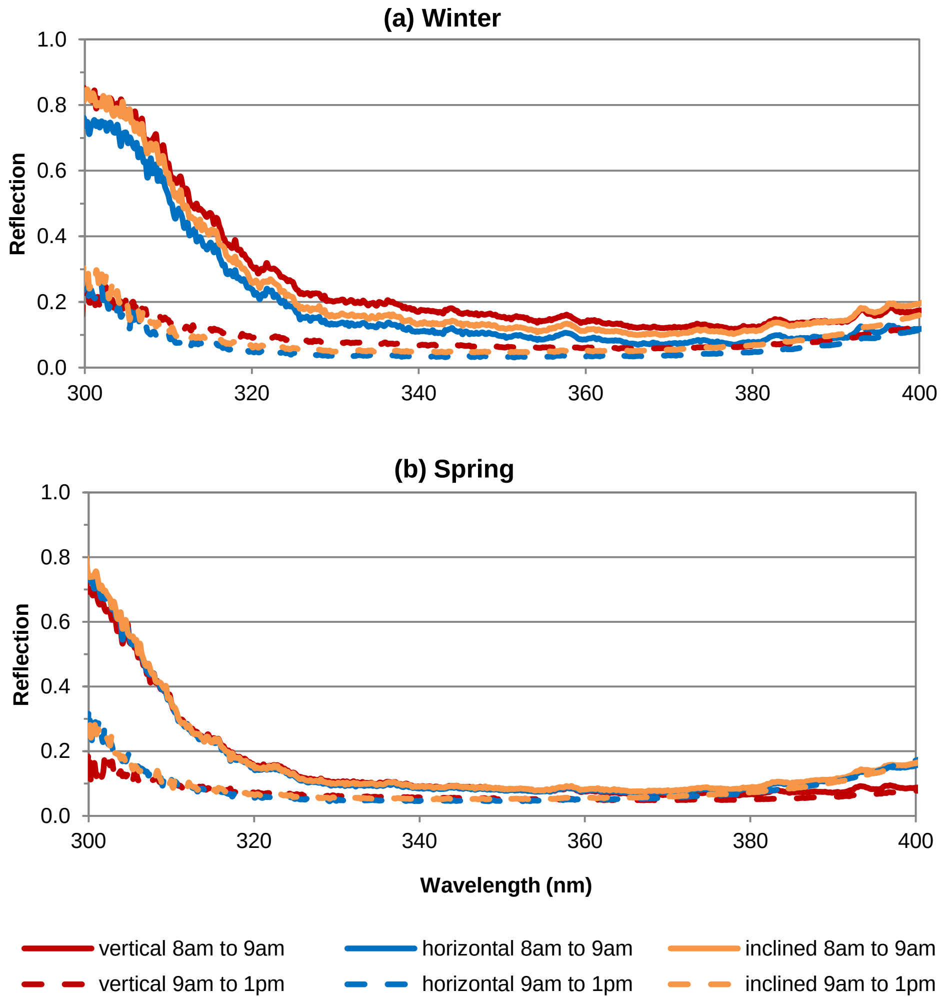

Figure 3.43 - Average reflection for cream corrugated for horizontal and north facing vertical and inclined surfaces for varying SZA and SAA in (a) Winter 2010 and (b) Spring 2010.

3.2.3.5 Pale green trapezoidal

Figure 3.44 displays the erythemal reflection ratio data, and the grouped SZA is plotted in Figure 3.45. Comparison of the grouped data for vertical, horizontal and inclined data is presented in Figure 3.46, where it appears the average vertical data is slightly larger than both the inclined and horizontal data. Figure 3.47 displays the minimum, maximum and average, while Figure 3.48 displays the average spectral reflection per measurement session. Figure 3.49 displays the averages obtained in comparing the data for spring and winter in 2010.

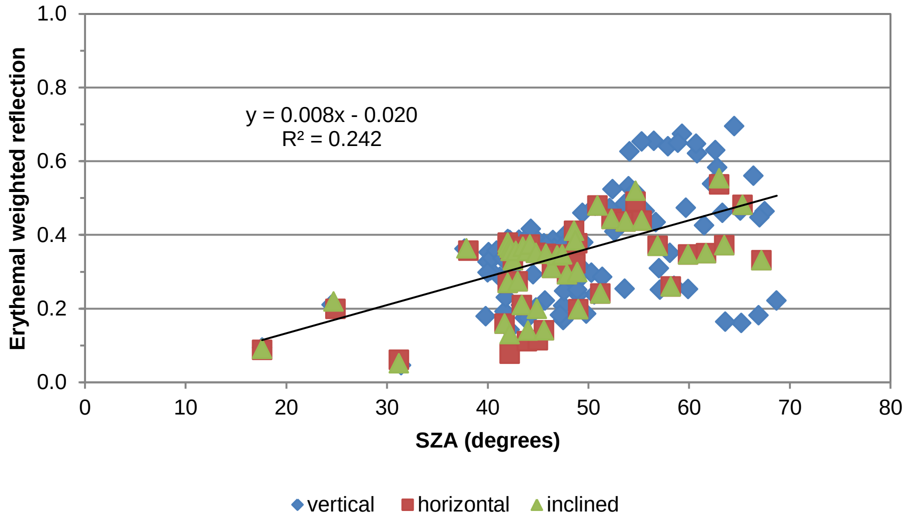

Figure 3.44 - Erythemal weighted reflection from a north facing vertical pale green trapezoidal surface over a variety of SZA with predicted model of best fit for vertical data.

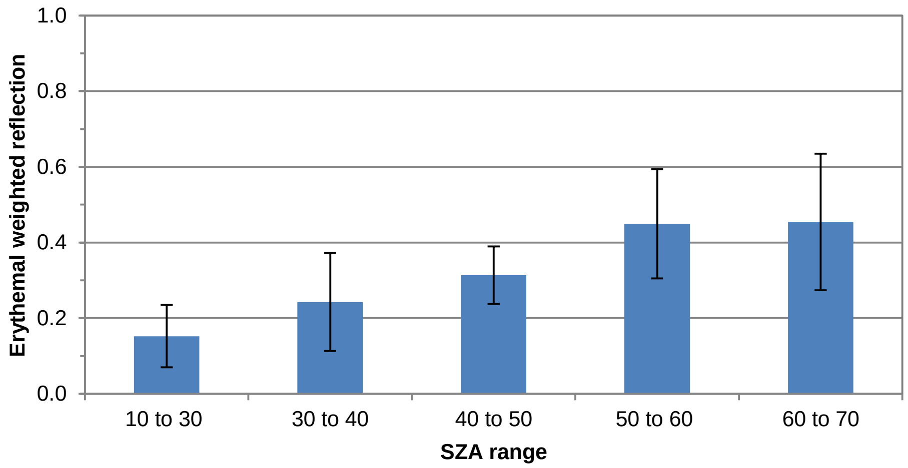

Figure 3.45 - Average ratio of erythemal reflected irradiance to erythemal direct irradiance for different SZA ranges for pale green trapezoidal (2008 to 2010).

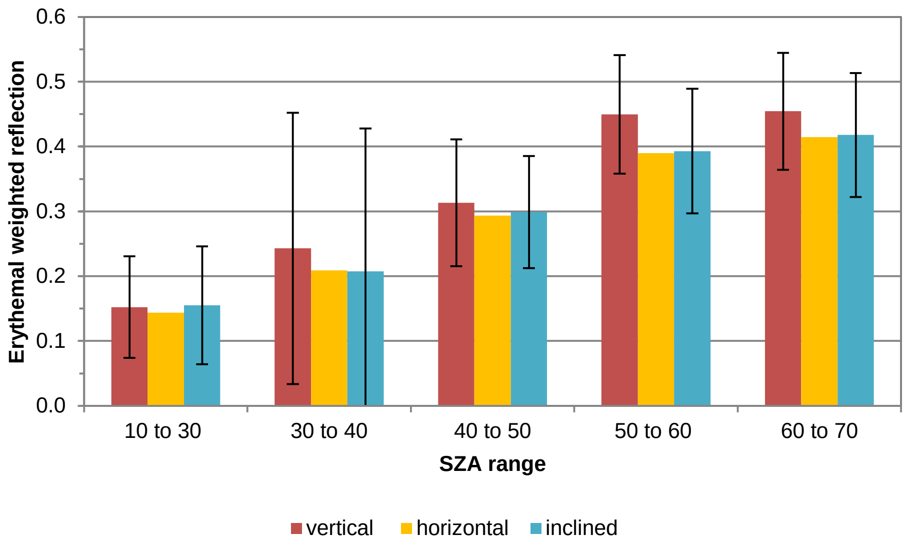

Figure 3.46 - Average ratio of erythemal reflected irradiance to erythemal direct irradiance for vertical, inclined and horizontal zinc aluminium trapezoidal surfaces for varying SZA (2008 to 2010) with standard deviation represented by the error bars.

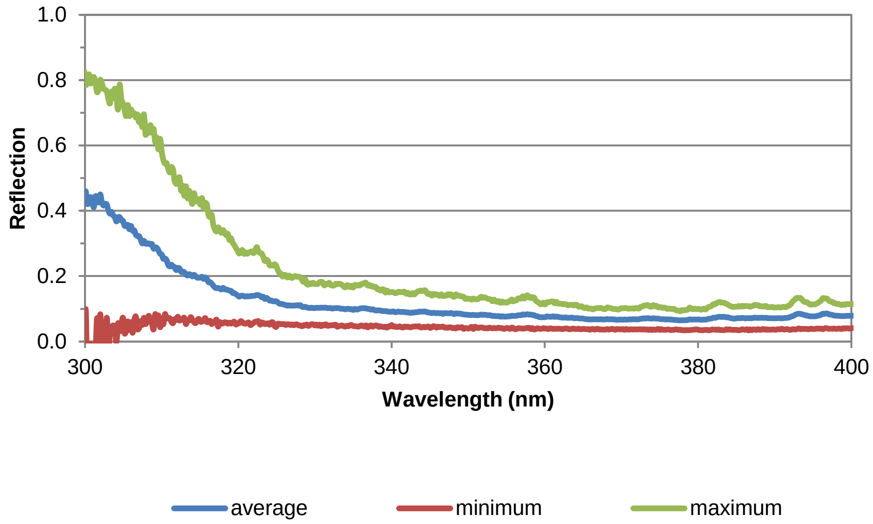

Figure 3.47 - Average, minimum and maximum reflection from a pale green trapezoidal vertical surface during Winter and Spring 2010.

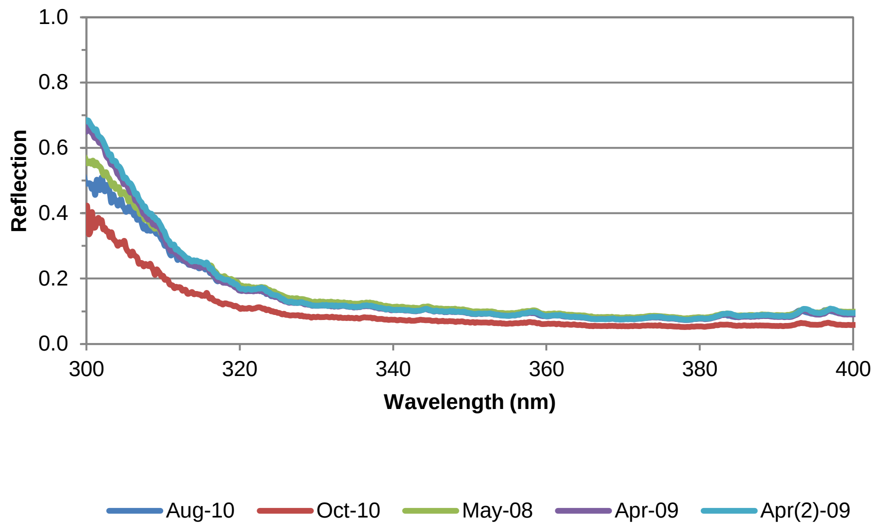

Figure 3.48 - Average daily reflection from pale green trapezoidal vertical north facing surface for all measurement sessions.

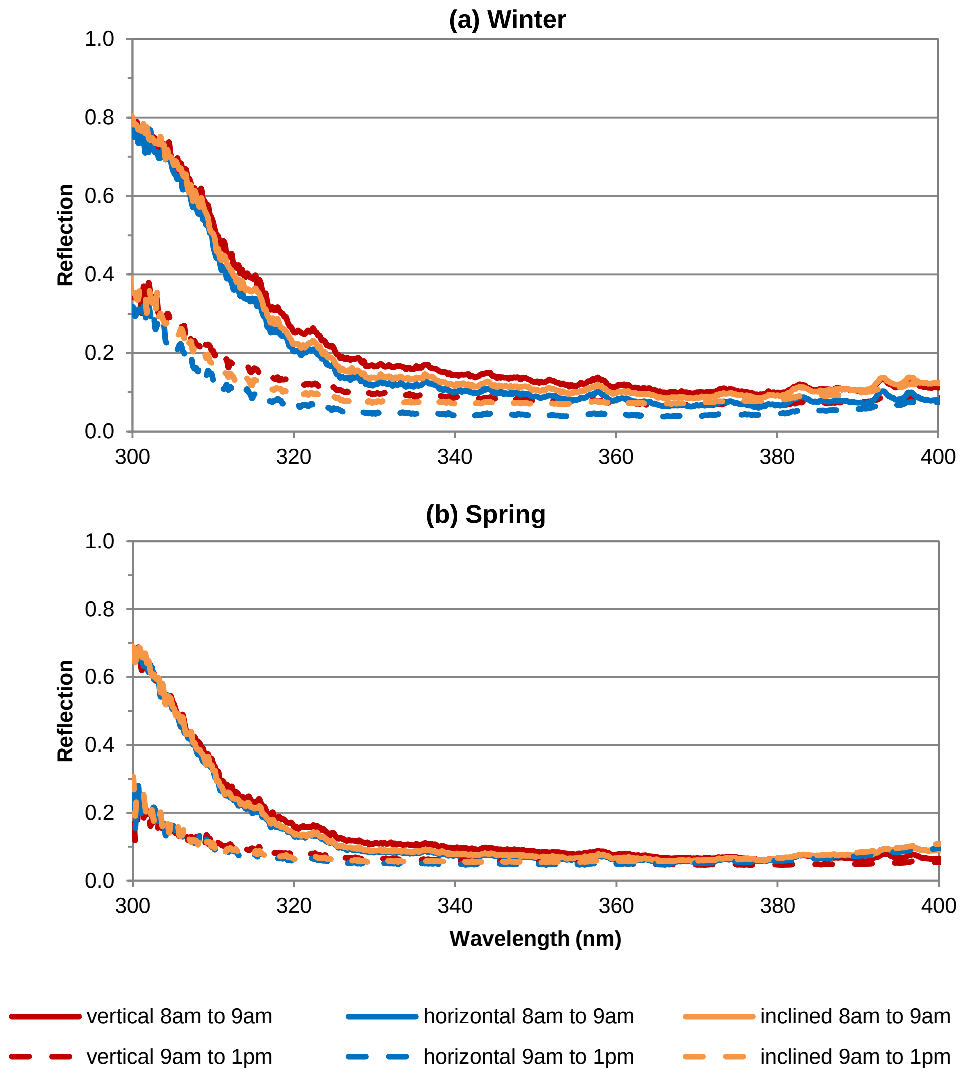

Figure 3.49 - Average reflection for pale green trapezoidal for horizontal and north facing vertical and inclined surfaces for varying SZA and SAA in (a)Winter 2010 and (b) Spring 2010.

3.2.3.6 Remaining surface types

The results found for the remaining surface types can be found in Appendix 7.2, due to the similarity found between all the remaining surface types and the cream trapezoidal, cream corrugated and pale green trapezoidal surfaces.

From the data supplied in Appendix 7.2, the following charts display the similarities between the reflection of the surfaces investigated using the average spectral reflection for a given surface. The average daily reflection is presented in Figure 3.50 (all SZA ranging from 70.3° to 42° for winter and 53.8° to 17.6° for spring) and the smaller SZA average (SZA range of 50.7° to 42° for winter and 38.6° to 17.6°) in Figure 3.51.

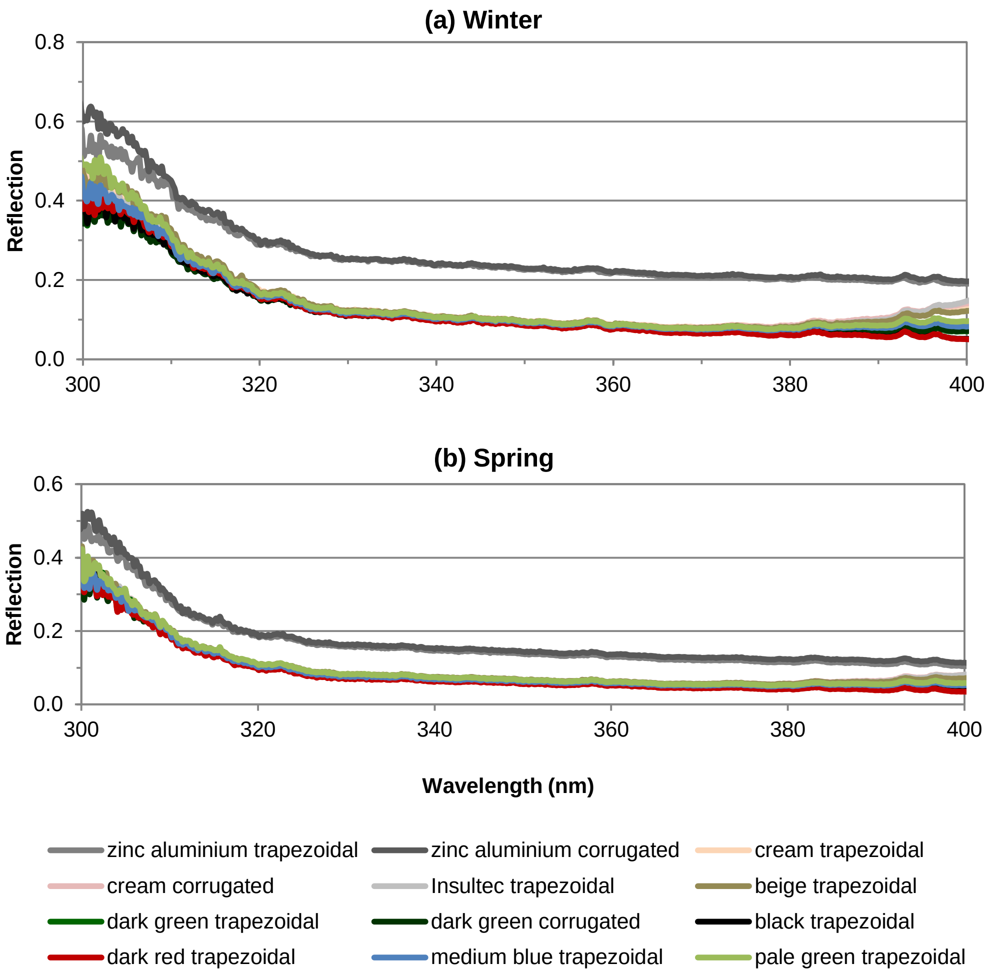

Figure 3.50 – Average daily reflection from vertical north facing surface (all types) for measurements made in August (winter SZA range 70.3° to 42°) and October 2010 (spring SZA range 53.8° to 17.6°).

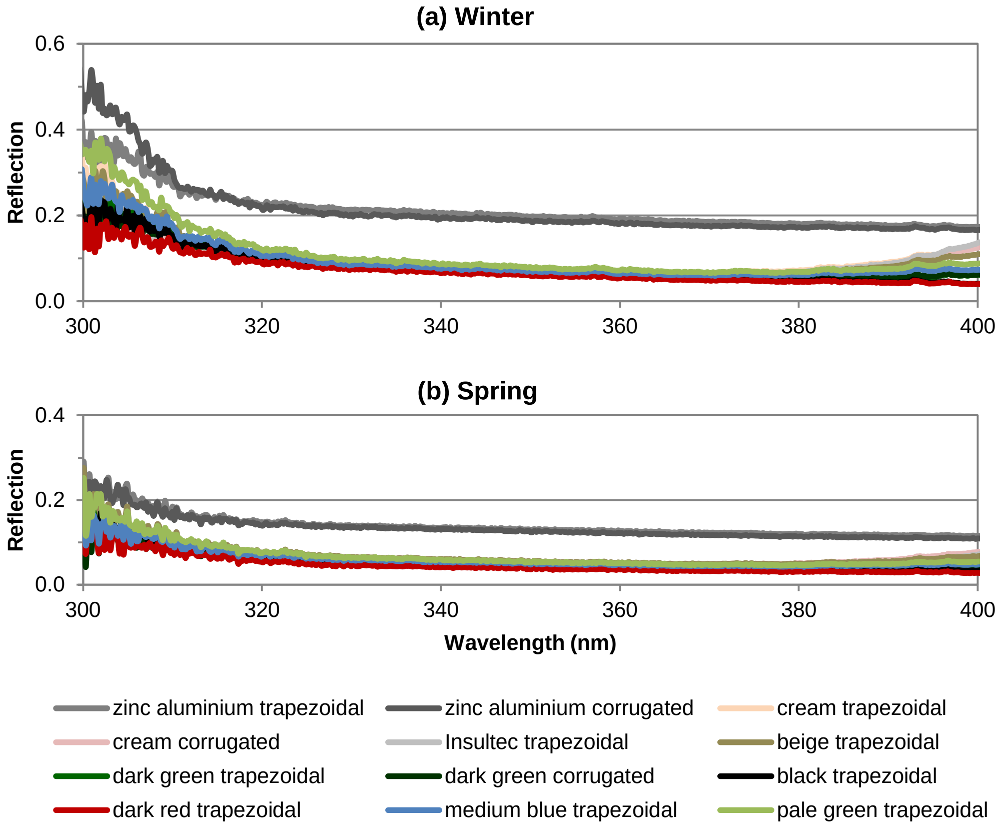

Figure 3.51 - Average reflection from 9 am to 1 pm each day for vertical north facing surface (all types) for measurements made in August (winter SZA range 50.7° to 42°) and October 2010 (spring SZA range 38.6° to 17.6°).

3.2.4 Other surface types *in situ*

A number of surface types in a variety of orientations were investigated for spectral reflection. This section summarizes the results found for these surfaces.

3.2.4.1 Non-vertical surfaces

3.2.4.1.1 Galvanised steel

The galvanized steel was located on the top of a building at USQ, inclined at 5.1° towards the east and was a part of a protective structure. A range of averaged spectral reflections is shown in Figure 3.52.

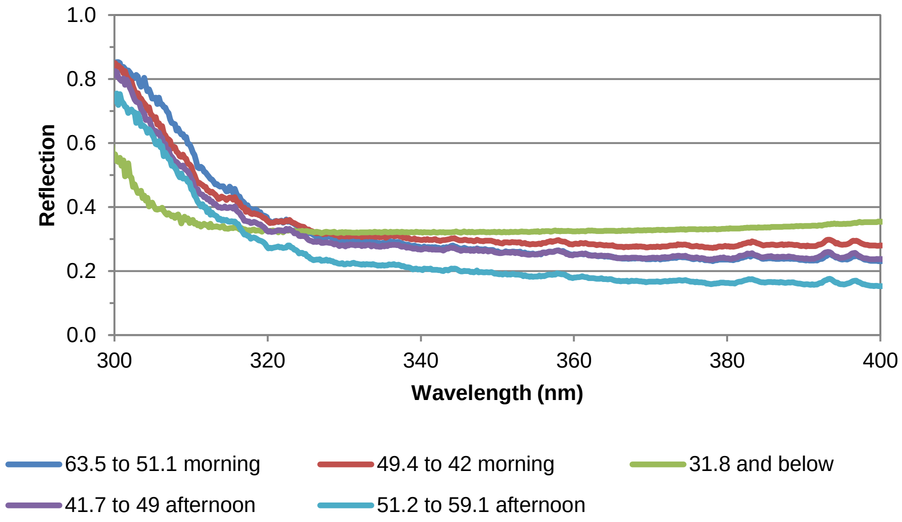

Figure 3.52 - Average reflections for galvanised steel inclined at 5.1° to the east, for a range of SZA and SAA.

3.2.4.1.2 Grey coated trapezoidal

The grey coated trapezoidal surface was the actual roof of the building at USQ on which the scanning spectroradiometer is located. The averaged spectral reflections are shown in Figure 3.53.

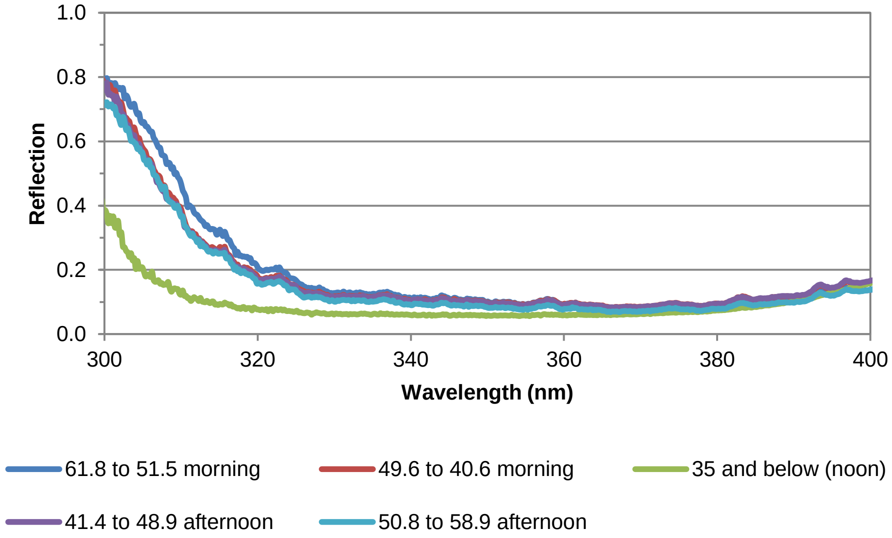

Figure 3.53 - Average reflection for horizontal grey trapezoidal, for a range of SZA and SAA.

3.2.4.1.3 Transparent plastic

The transparent plastic was a part of a skylight cover located on the top of a building at USQ. Two sensor positions were used and two sides of the skylight were used (north facing and west facing). The skylight was a square based pyramid with the sides inclined at 45°. The averaged spectral reflections are shown in Figure 3.54.

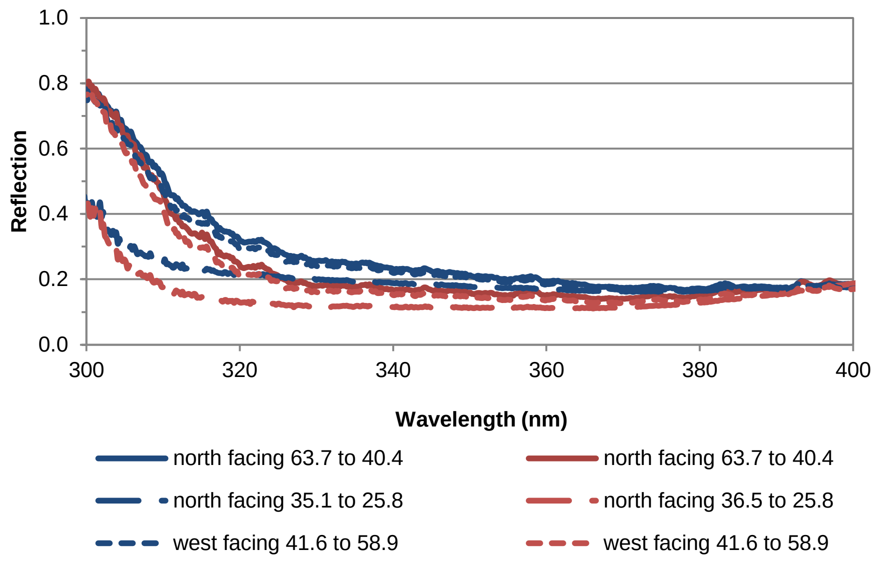

Figure 3.54 – Average reflection per wavelength for transparent plastic (inclined 45° to north and west) for three different SZA groups and two sensor positions (dark blue for low vertically oriented sensor and red for normal to inclined surface).

3.2.4.2 Vertical surfaces

3.2.4.2.1 Tinted glass

Reflection measurements made for dark tinted glass could only be made when direct sunlight fell on the local areas with dark tinted glass. In most cases, dark tinted glass has been used in conjunction with buildings incorporating broad overhangs and will often not receive direct sunlight. For this west facing surface, direct sunlight occurs from ground level up to about one and half metres from the ground for hourly periods in the afternoon (depending on time of year), until the sun passes behind trees opposite to the location of the dark tinted glass. Therefore a range of SZA measurements for tinted glass was not obtained. The building was located on the campus grounds at USQ Toowoomba. Due to the limited time period to make measurements, the surface was investigated for a variety of reflection distance measurements as well as a small SZA and SAA variation. Figure 3.55 presents the spectral reflection variation with distance, and Figure 3.56 presents the variation with SZA and SAA.

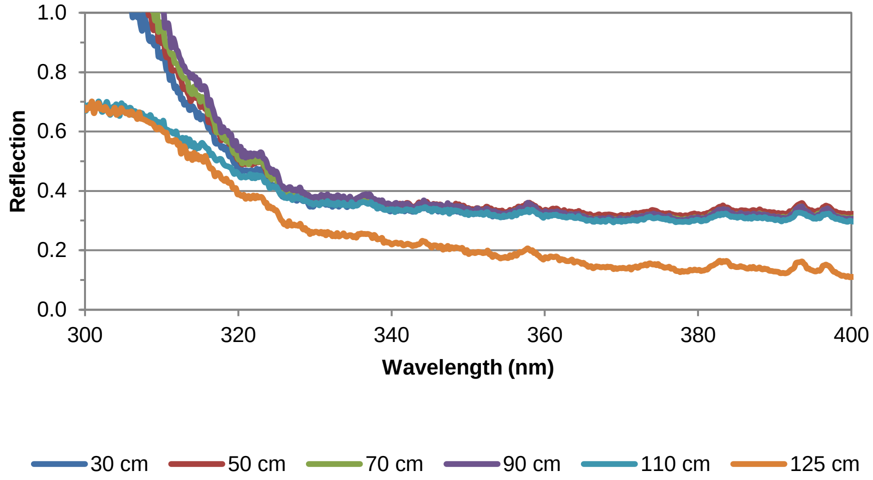

Figure 3.55 - Reflection per wavelength from west facing dark tinted glass at varying distances from glass surface measured at SZA of 63° and SAA of -57°.

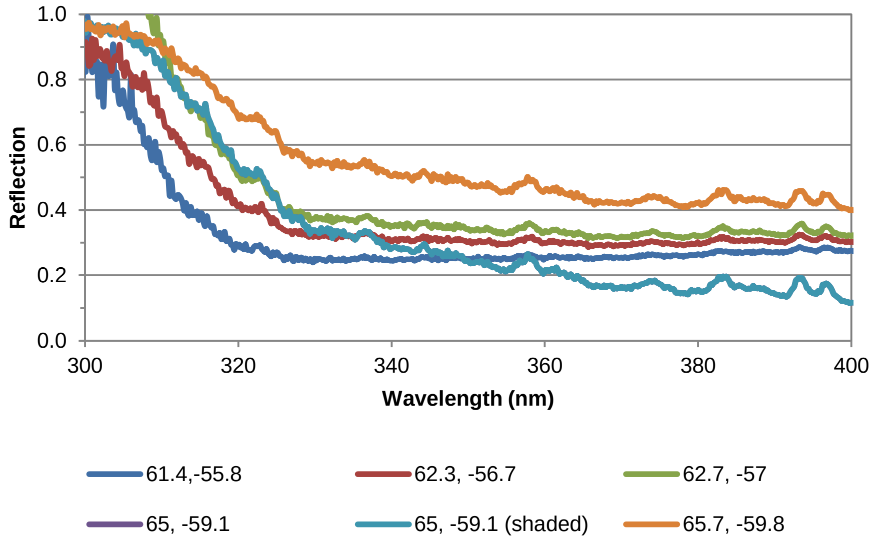

Figure 3.56 - Reflection per wavelength from west facing dark tinted glass at 0.5 m over small variation in SZA and SAA.

3.2.4.2.2 White painted fibro board

The white painted fibro board was the wall structure of a building located on the USQ Toowoomba campus. The building is built off the ground and has no surrounding gardens to impair measurements. Figure 3.57 displays the range of spectral reflections measured from this surface type.

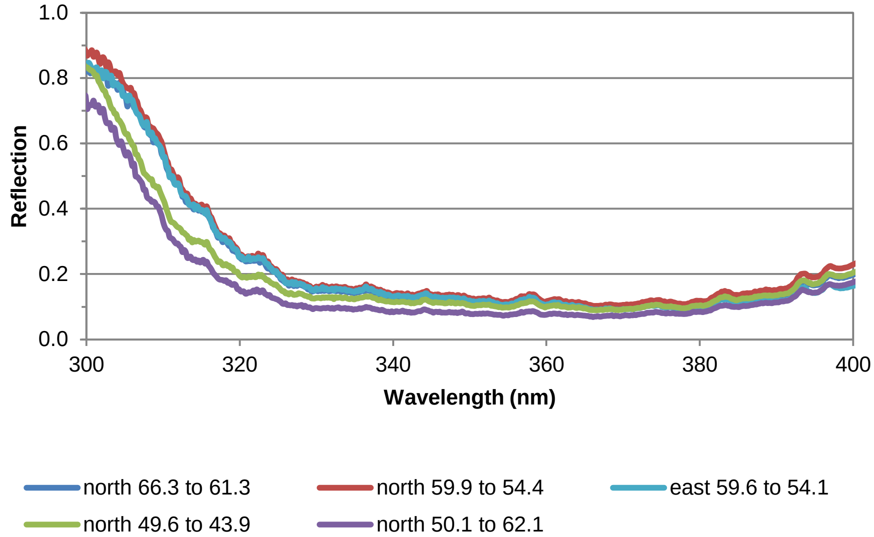

Figure 3.57 - Average reflection per wavelength for given SZA groups for north facing surface (all day) and east facing surface (morning).

3.2.4.2.3 Red brick

The red brick is part of a wall of a recreational centre building located on the USQ Toowoomba campus. Figure 3.58 displays the spectral reflection measurements from this surface type.

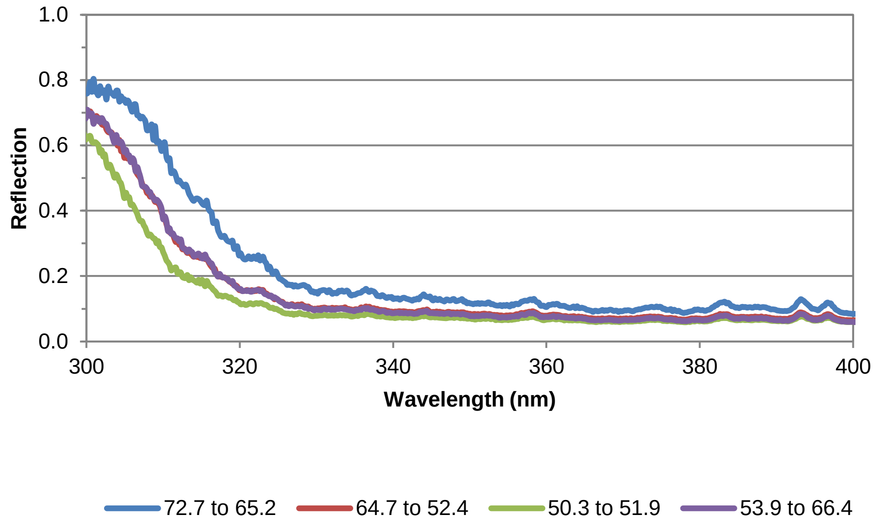

Figure 3.58 –Average reflection per wavelength for given SZA groups for north facing surface (all day) from red brick.

3.3 Quantification of biological effect of UV exposure due to vertical UV reflective surfaces

Results obtained in Sections 3.2.2 and Sections 3.2.3 indicate that some types of metal surface sheeting are more reflective within the UV spectrum than other types. From the data it appears that zinc aluminium coated steel has a higher reflectivity within the waveband of 300 nm to 400 nm than painted coated steel. It is also observed that the colour of the paint coated steel has a low influence on reflection of UV radiation. The type of sheeting used, specifically corrugated or trapezoidal shaped sheeting appears to also be of low influence when comparing the same type of coated sheeting (for example when both metal sheeting are coated with zinc aluminium). As a result of this observation, only a few types of this metal sheeting was explored in quantifying the influence to UV exposure, as it was anticipated that similar results would be obtained for similar types of metal sheeting. The sheeting surfaces that were explored for influences to UV exposure were selected based on the observed use of the sheeting types in residential and industrial areas. Industrial areas may use either a zinc aluminium coated steel or paint coated steel or a combination of both. Residential areas tend to use more painted coated steel, however, it is still relatively common to see galvanized or zinc aluminium coated steel used on rooftops (an inclined surface) in residential areas. The most commonly used paint coated steel sheeting tend to be paler colours in residential areas (in both building such as sheds, and fences) athough darker colours are appearing to be more fashionable in newer built dwellings (such as roofs). The colours chosen for these studies are pale green and cream paint coated steel sheeting, and zinc aluminium trapezoidal and corrugated sheeting. The ozone column above Toowoomba for each day of measurement was obtained where available from the OMI (Ozone Monitoring

Instrument) located on the Aura spacecraft maintained by NASA from (http://jwocky.gsfc.nasa.gov/teacher/ozone_overhead_v8.html).

3.3.1 Investigating influence of reflective wall surfaces on UV exposure in Autumn 2008

Using the calculated calibration curves of the dosimeters for each hour of exposure, the erythemal exposure for each dosimeter attached to each head form was calculated. The erythemal exposure corresponding to each dosimeter was then averaged for an entire head form and compared over the hourly intervals. This data has been published in Turner & Parisi (2009).

3.3.1.1 Zinc aluminium trapezoidal

The measurement of erythemal exposure due to the influence of vertical surfaces was carried out over two days, 10 and 11 May, 2008 using SED (standard erythemal dose). OMI ozone was recorded at 259 DU for 10 May and 255 DU for 11 May. The weather was similar with low to no cloud cover throughout each day. The average erythemal exposure for thirteen dosimeters per head form is shown in Figure 3.59 (a). The averaging of these values incorporates exposures experienced by dosimeters that were not orientated towards the direction of a wall (such as the back of the head or the back of the neck), and hence may affect the influence of the presence of a nearby wall on dosimeters that are directly influenced.

The dosimeter positions that are most likely to be influenced by the presence of a nearby wall are those located on the face, and dosimeters that are on the side of the body facing the wall. These include the forehead, nose, chin and chest, the cheeks and ears. The shoulders are also likely to be influenced, but as the positioning of the shoulder dosimeters are mostly horizontal, will also be experiencing mostly direct exposure from the sun, and hence have not been considered in section (b) of Figure 3.59, which displays the average exposure for the eight dosimeters on the frontal side of the body. It is evident here that whilst exposures are clearly lower compared to the average of the total of body site exposures, the influence of a nearby reflective wall is more pronounced. In section (c) of Figure 3.59, the average exposure for the five facial dosimeter locations (forehead, nose, chin and cheeks) is presented per hour of exposure. The exposure values are little changed from section (b), but the influence of the nearby wall is more pronounced again.

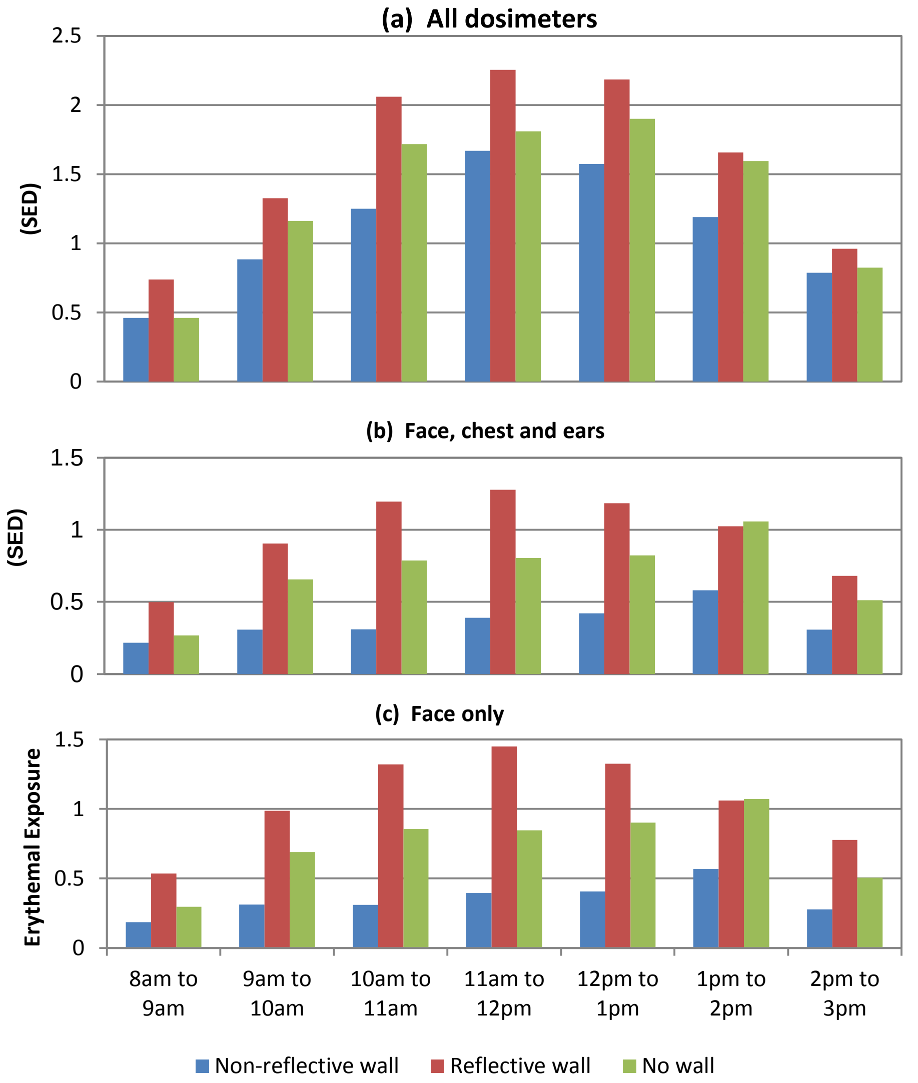

Figure 3.59 - Average erythemal exposure of three groups (consisting of thirteen, eight and five respectively) of dosimeters per head form over intervals of hourly measurement for zinc aluminium trapezoidal wall, a non-reflective wall and no wall.

3.3.1.2 Pale green trapezoidal

The measurement of the erythemal exposure due to the influence of vertical wall surfaces for a pale green (paint coated) trapezoidal surface was carried out over two days, 18 and 20 May, 2008. OMI ozone was recorded at 275 DU for 18 May and 252 DU for 20 May. These two days had similar weather conditions (low to no cloud cover). The same breakdown of data used for zinc aluminium trapezoidal has been used in all the data, and for this surface type is presented in Figure 3.60.

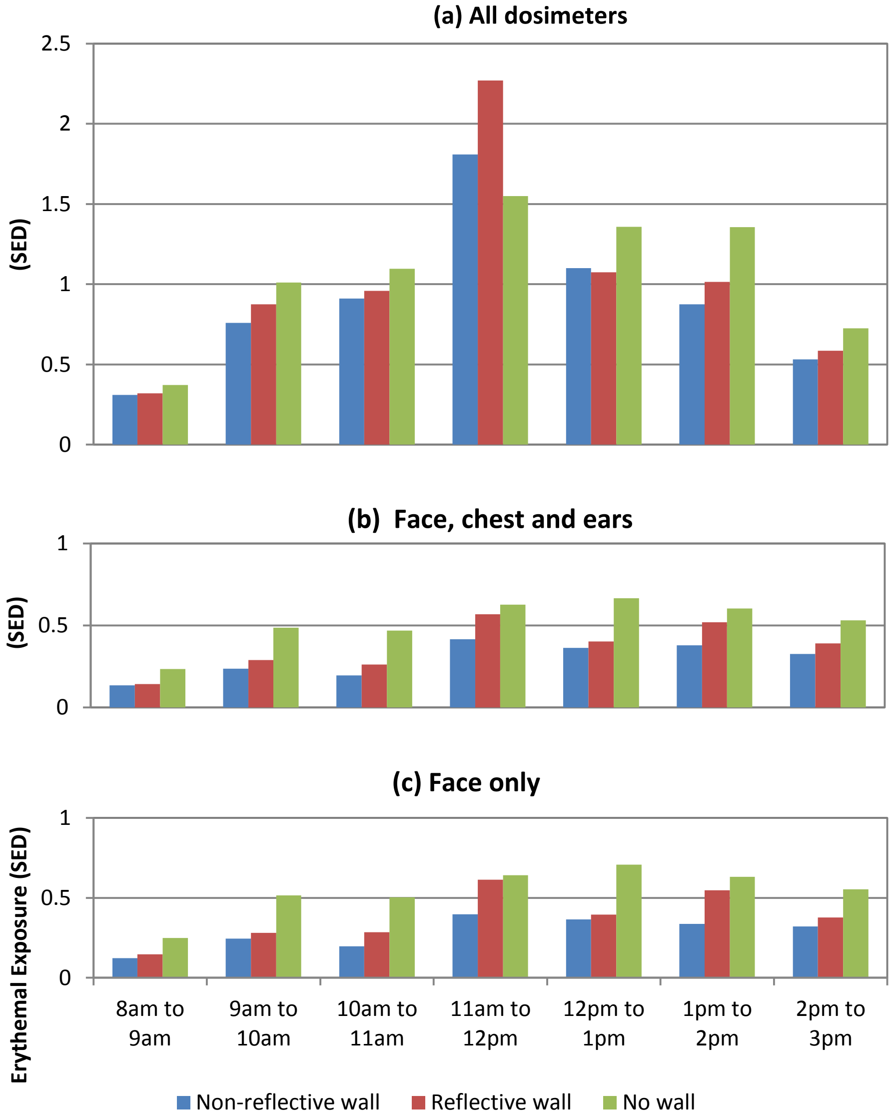

Figure 3.60 – Average erythemal exposure of three groups (consisting of thirteen, eight and five respectively) of dosimeters per head form over intervals of hourly measurement for pale green trapezoidal wall, a non-reflective wall and no wall.

3.3.1.3 Cream trapezoidal

Half a day of erythemal exposure measurements only were obtained for cream trapezoidal sheeting measured on 27 May 2008 due to the unstable weather conditions following the day of initial measurement. OMI ozone was recorded at 263 DU. Cloud cover was present early in the morning, and also obscured the sun for half of the final interval of the day. The data is presented in Figure 3.61.

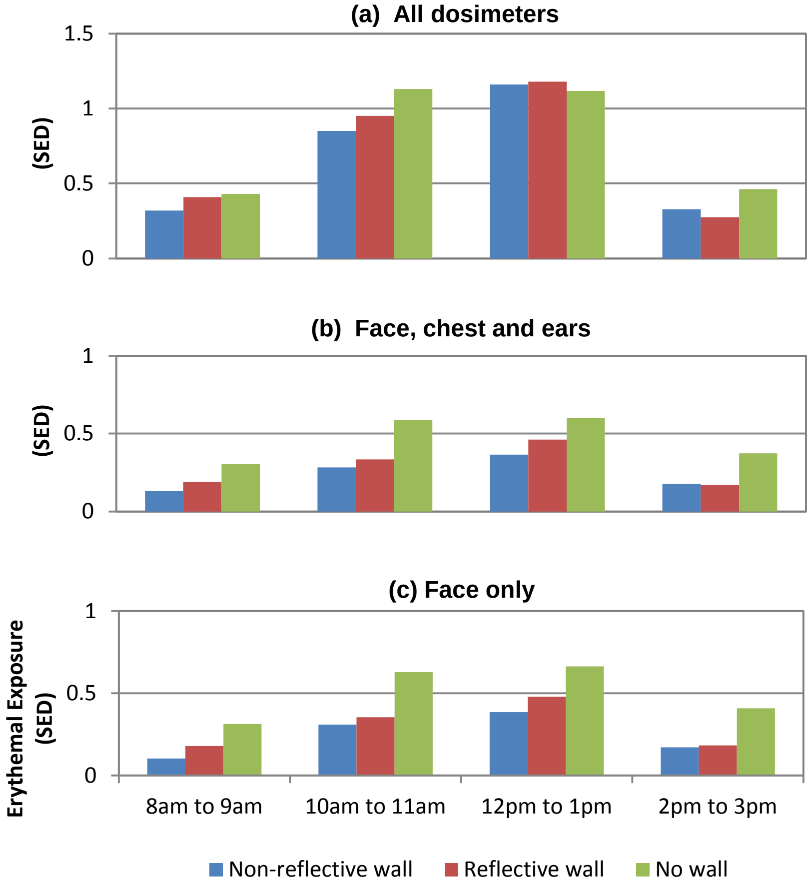

Figure 3.61 - Average erythemal exposure of three groups (consisting of thirteen, eight and five respectively) of dosimeters per head form over intervals of hourly measurement for cream trapezoidal wall, a non-reflective wall and no wall.

3.3.1.4 Comparing influence of erythemal exposure due to presence of vertical surfaces

The average daily ratio of exposure from reflective to no wall exposure per individual dosimeter position on the head form was compared and is presented in Figure 3.62. The standard error of 10 % for dosimeters has been applied.

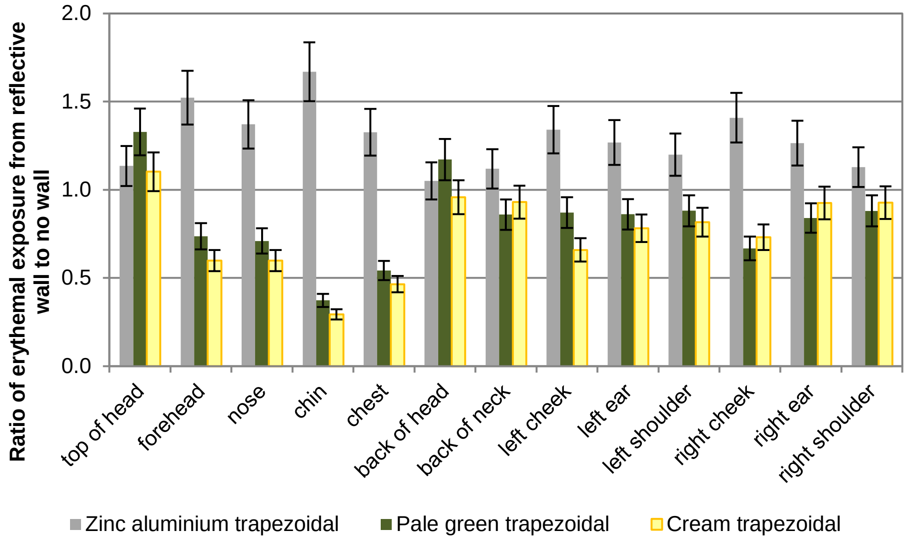

Figure 3.62 - Average ratio of erythemal exposure measured on head forms from reflective wall to no wall according to dosimeter position.

All the data was compared by calculating ratios of particular exposure groups, such as comparing the exposure obtained for each site in the vicinity of a reflective wall compared to no wall present. The data has been tabulated in Table 3.3.

Table 3.3 - Comparison of the ratios of average erythemal exposure received for head forms located near reflective wall, non-reflective wall and no wall, for different dosimeter average groupings in Autumn 2008.

	8 am to 9 am	9 am to 10 am	10 am to 11 am	11 am to 12 pm	12 pm to 1 pm	1 pm to 2 pm	2 pm to 3 pm	Daily average
Zinc Aluminium trapezoidal								
All features average								
Reflective to no wall	1.60	1.14	1.20	1.24	1.15	1.04	1.17	1.22
Reflective to non-reflective	1.60	1.50	1.65	1.35	1.39	1.39	1.22	1.44
Non-reflective to no wall	1.00	0.76	0.73	0.92	0.83	0.75	0.96	0.85
Face+ chest + ears average								
Reflective to no wall	1.85	1.38	1.52	1.58	1.44	0.97	1.33	1.44
Reflective to non-reflective	2.30	2.94	3.87	3.27	2.82	1.76	2.20	2.74
Non-reflective to no wall	0.80	0.47	0.39	0.48	0.51	0.55	0.60	0.55
Facial features (only) average								
Reflective to no wall	1.81	1.43	1.54	1.71	1.47	0.99	1.54	1.50
Reflective to non-reflective	2.88	3.15	4.24	3.65	3.26	1.87	2.79	3.12
Non-reflective to no wall	0.63	0.45	0.36	0.47	0.45	0.53	0.55	0.49
Pale green trapezoidal								
All features average								
Reflective to no wall	0.86	0.86	0.87	1.46	0.79	0.75	0.80	0.92
Reflective to non-reflective	1.03	1.15	1.05	1.25	0.98	1.16	1.10	1.10
Non-reflective to no wall	0.83	0.75	0.83	1.17	0.8	0.64	0.73	0.82
Face + chest + ears average								
Reflective to no wall	0.61	0.59	0.56	0.91	0.60	0.86	0.73	0.70
Reflective to non-reflective	1.07	1.22	1.34	1.37	1.12	1.37	1.20	1.24
Non-reflective to no wall	0.57	0.49	0.42	0.66	0.55	0.63	0.61	0.56
Facial features (only) average								
Reflective to no wall	0.59	0.55	0.57	0.96	0.56	0.87	0.68	0.68
Reflective to non-reflective	1.19	1.15	1.45	1.54	1.08	1.62	1.17	1.31
Non-reflective to no wall	0.49	0.47	0.39	0.62	0.52	0.54	0.58	0.52
Cream trapezoidal								
All features average								
Reflective to no wall	0.95		0.84		1.05		0.59	0.86
Reflective to non-reflective	1.28		1.12		1.02		0.84	1.06
Non-reflective to no wall	0.74		0.75		1.04		0.71	0.81
Face + chest + ears average								
Reflective to no wall	0.63		0.57		0.77		0.46	0.61
Reflective to non-reflective	1.47		1.18		1.26		0.96	1.22
Non-reflective to no wall	0.43		0.48		0.61		0.48	0.50
Facial features (only) average								
Reflective to no wall	0.57		0.56		0.72		0.45	0.58
Reflective to non-reflective	1.73		1.14		1.24		1.06	1.29
Non-reflective to no wall	0.33		0.49		0.58		0.42	0.46

3.3.2 Investigating influence of reflective wall surfaces on UV exposure in Winter 2008

3.3.2.1 Cream trapezoidal

The erythemal exposure measurements for cream trapezoidal were obtained on 25 and 26 August 2008. OMI ozone was recorded at 288 DU on 26 August but no ozone was recorded for 25 August. The weather conditions included clear skies in the earlier morning intervals with sporadic cloud cover for middle of day intervals. The afternoon intervals had up to 50% cloud cover with the sun obscured for some of the time. Both days had similar weather conditions. The data is presented in Figure 3.63 and Table 3.4.

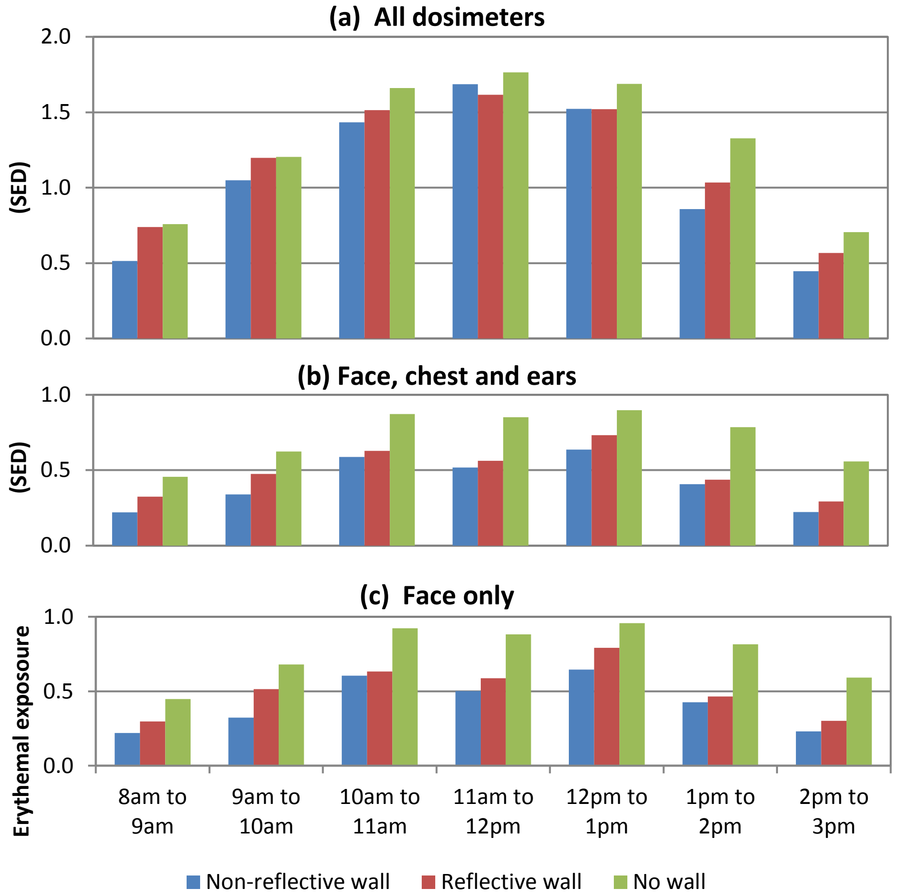

Figure 3.63 - Average erythemal exposure of three groups (consisting of thirteen, eight and five respectively) of dosimeters per head form over intervals of hourly measurement for cream trapezoidal wall, a non-reflective wall and no wall in winter.

Table 3.4 – Ratios of average erythemal exposure received for head forms located near cream trapezoidal reflective, non-reflective and no wall, for different dosimeter groupings, Winter 2008.

	8 am to 9 am	9 am to 10 am	10 am to 11 am	11 am to 12 pm	12 pm to 1 pm	1 pm to 2 pm	2 pm to 3 pm	Daily average
Cream trapezoidal								
All features average								
Reflective to no wall	0.97	1.00	0.91	0.92	0.90	0.78	0.80	0.90
Reflective to non-reflective	1.44	1.14	1.06	0.96	1.00	1.21	1.27	1.15
Non-reflective to no wall	0.68	0.87	0.86	0.96	0.90	0.65	0.63	0.79
Face + chest + ears average								
Reflective to no wall	0.71	0.76	0.72	0.66	0.82	0.56	0.52	0.68
Reflective to non-reflective	1.47	1.41	1.07	1.09	1.15	1.07	1.31	1.22
Non-reflective to no wall	0.48	0.54	0.67	0.61	0.71	0.52	0.40	0.56
Facial features (only) average								
Reflective to no wall	0.67	0.76	0.68	0.67	0.83	0.57	0.51	0.67
Reflective to non-reflective	1.35	1.60	1.04	1.17	1.23	1.09	1.31	1.26
Non-reflective to no wall	0.49	0.47	0.66	0.57	0.68	0.52	0.39	0.54

3.3.3 Investigating influence of reflective wall surfaces on UV exposure in Spring 2008

3.3.3.1 Zinc aluminium corrugated

The erythemal exposure measurements for a zinc aluminium corrugated wall were made over two days, 30 September 2008 and 7 October 2008, with some cloud present on 30 September and no cloud cover on 7 October (Figure 3.64). The OMI ozone was recorded at 292 DU for 10 November and 282 DU for 11 November.

The erythemal exposure measurements for zinc aluminium corrugated were repeated on 10 and 11 November 2008 (late spring) with this time of year in Australia already approaching conditions experienced in summer. The weather conditions for each day started relatively clear, but slowly increased in cloud cover until it reached approximately 70% cloud cover on 10 November for the 2 pm to 3 pm interval. Unfortunately, the Bentham spectroradiometer data could not be accessed due to a technical issue. The erythemal dosimeter calibration could not be calculated, but the dosimeter calibration curve approximates a cubic polynomial, therefore the relative proportion of UV exposure received per head form can be evaluated.

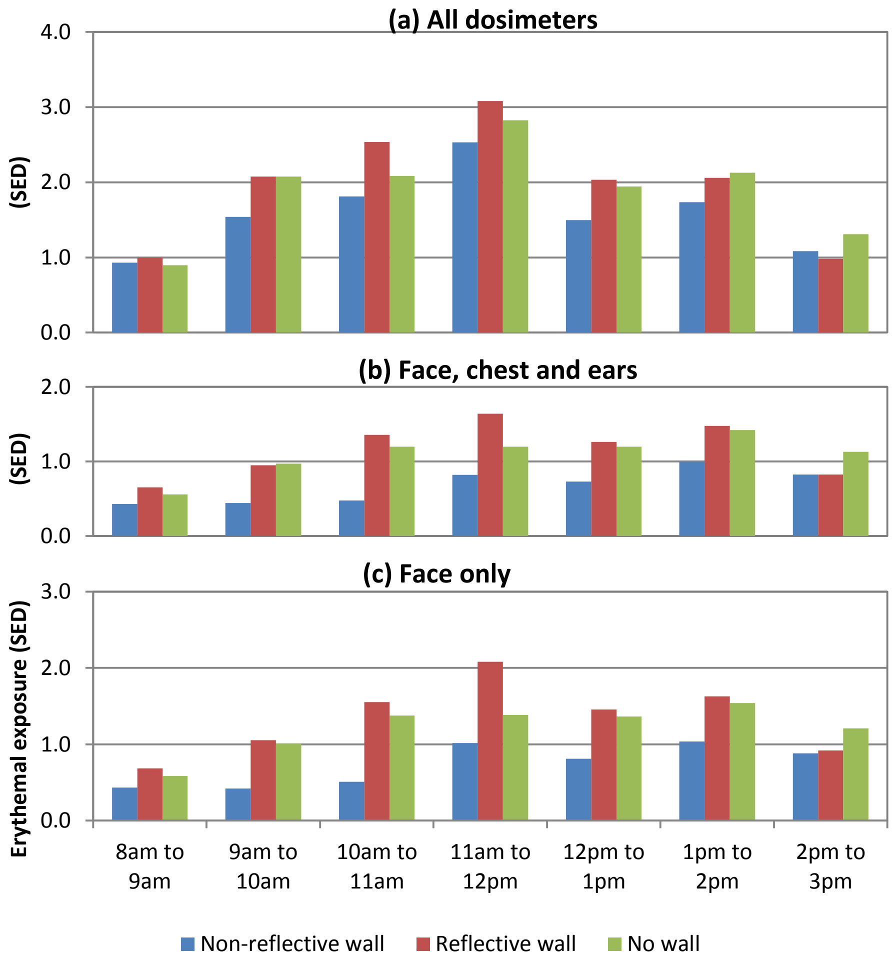

Figure 3.64 - Average erythemal exposure of three groups (consisting of thirteen, eight and five respectively) of dosimeters per head form over intervals of hourly measurement for zinc aluminium corrugated wall, a non-reflective wall and no wall in spring.

According to Diffey (1989) the following relationship can approximate the erythemally weighted UV irradiance incurred by a dosimeter

$$UV_{ery} = k[9(\Delta A_{330})^3 + (\Delta A_{330})^2 + \Delta A_{330}]$$

where k is a calibration constant that is calculated through calibration of the dosimeters (Parisi, Sabburg & Kimlin 2004a). Any data calculated will use the same value of k, which is consistent across all the data collected in the same session of measurement. When the ratio of two exposure measurements are taken, such as the unweighted exposures supplied in Figure 3.65, calculated using the above equation (where k is not known) the calibration constant cancels, indicating the data in Figure 3.65 is only useful when considered relative to one another. If only the ratio is required, the result should be enough to compare to the previous measurements made for zinc aluminium corrugated. There is no unit supplied for the data in Figure 3.65 since k is not known.

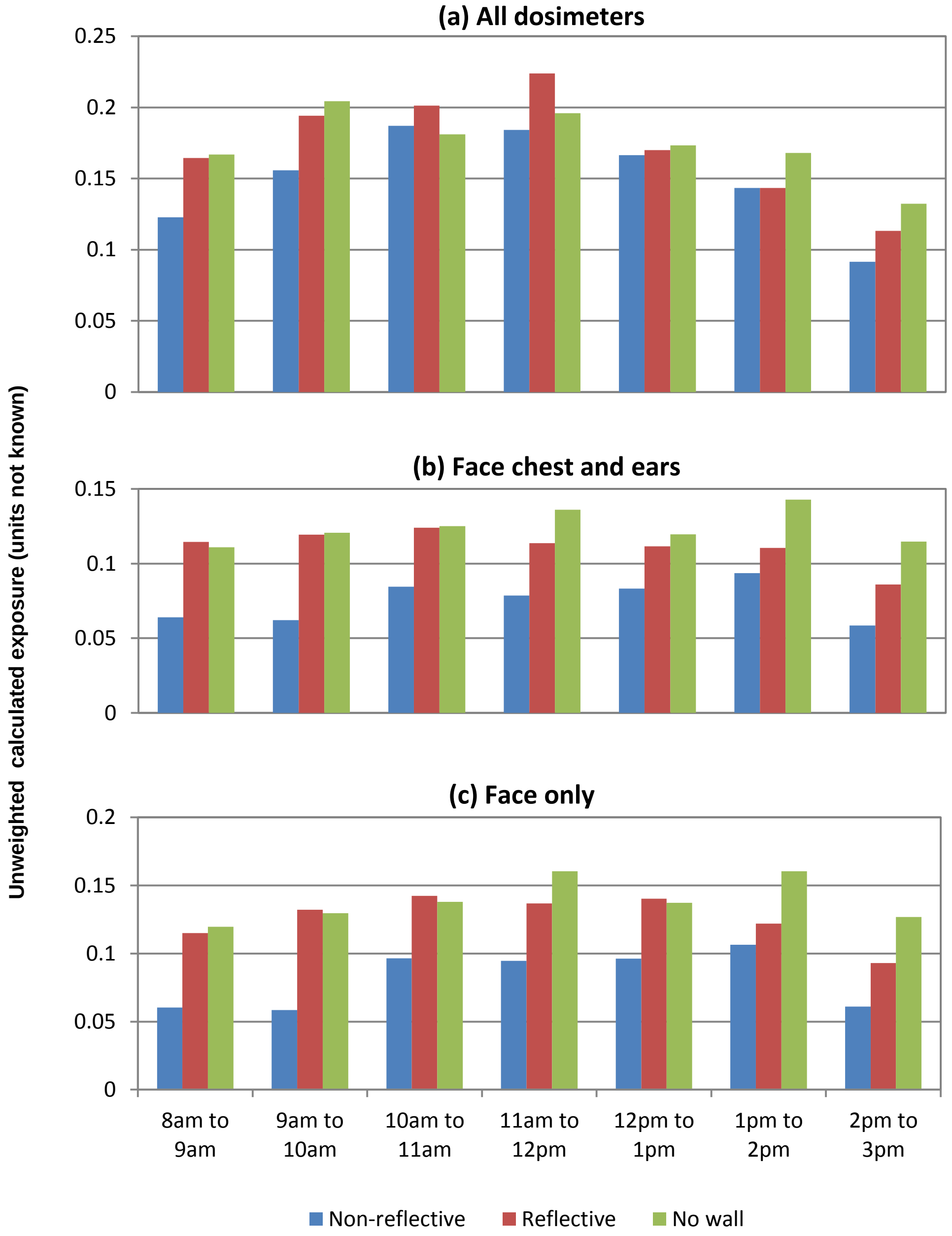

Figure 3.65 – Estimated unweighted exposure of three groups (consisting of thirteen, eight and five respectively) of dosimeters per head form over intervals of hourly measurement for zinc aluminium corrugated wall, a non-reflective wall and no wall.

3.3.3.2 Zinc aluminium trapezoidal

The erythemal exposure measurements for a zinc aluminium trapezoidal wall were made on 28 and 29 October 2008. Both days had low to no cloud cover. There was no OMI ozone recorded on 28 October, but was recorded at 285 DU on 29 October. The data is presented in Figure 3.66.

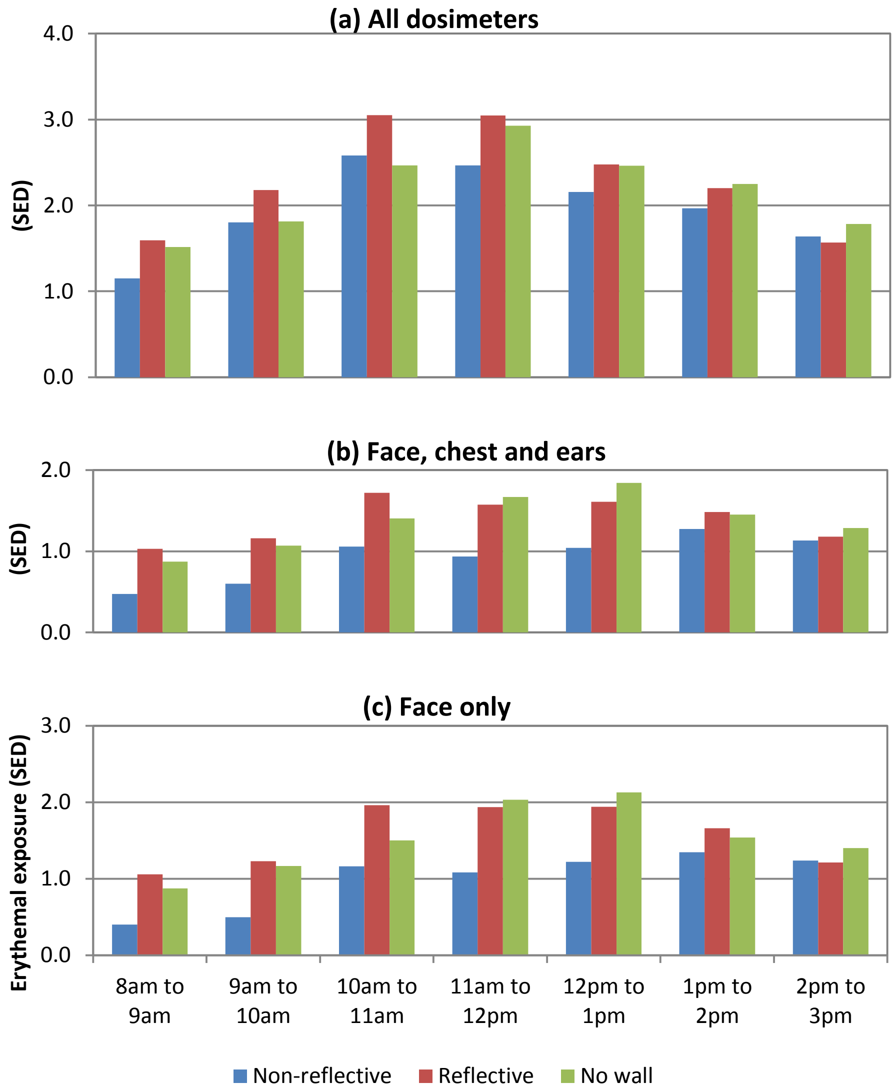

Figure 3.66 - Average erythemal exposure of three groups (consisting of thirteen, eight and five respectively) of dosimeters per head form over intervals of hourly measurement for zinc aluminium trapezoidal wall, a non-reflective wall and no wall in spring.

3.3.3.3 Comparison of surface type for Spring 2008

The average daily ratio of exposure from reflective to no wall exposure per individual dosimeter position on the head forms was compared for the surface types used in spring 2008 and is presented in Figure 3.67.

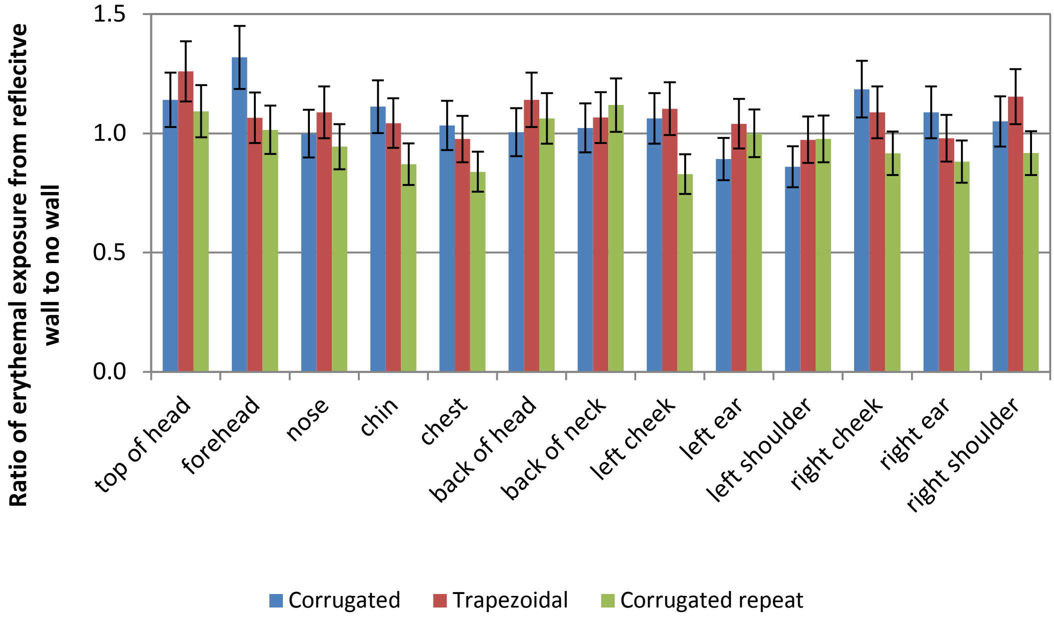

Figure 3.67 - Average ratio of erythemal exposure measured on head forms from reflective wall to no wall according to dosimeter position for zinc aluminium corrugated and zinc aluminium trapezoidal in Spring 2008 with 10% error.

All the data collected in spring 2008 was compared in terms of ratios of particular scenarios like those used in Table 3.3 and 3.4. This data is tabulated in Table 3.5.

Table 3.5 - Comparison of the ratios of average erythemal exposure received for head forms located near reflective wall, non-reflective wall and no wall, for different dosimeter average groupings in Spring 2008.

	8 am to 9 am	9 am to 10 am	10 am to 11 am	11 am to 12 pm	12 pm to 1 pm	1 pm to 2 pm	2 pm to 3 pm	Daily average
Zinc aluminium corrugated (early spring)								
All features average								
Reflective to no wall	1.12	1.00	1.22	1.09	1.05	0.97	0.75	1.03
Reflective to non-reflective	1.07	1.35	1.40	1.22	1.36	1.19	0.90	1.21
Non-reflective to no wall	1.04	0.74	0.87	0.90	0.77	0.82	0.83	0.85
Face + chest + ears average								
Reflective to no wall	1.16	0.98	1.14	1.37	1.05	1.04	0.73	1.07
Reflective to non-reflective	1.52	2.14	2.83	1.99	1.73	1.48	1.00	1.81
Non-reflective to no wall	0.77	0.46	0.40	0.69	0.61	0.70	0.73	0.62
Facial features (only) average								
Reflective to no wall	1.17	1.04	1.13	1.50	1.07	1.06	0.76	1.11
Reflective to non-reflective	1.58	2.51	3.06	2.05	1.80	1.57	1.04	1.94
Non-reflective to no wall	0.74	0.42	0.37	0.73	0.59	0.67	0.73	0.61
Zinc aluminium corrugated (late spring – early summer)								
All features average								
Reflective to no wall	0.98	0.95	1.1	1.14	0.98	0.85	0.86	0.98
Reflective to non-reflective	1.34	1.25	1.08	1.22	1.02	1.00	1.24	1.16
Non-reflective to no wall	0.74	0.76	1.03	0.94	0.96	0.85	0.69	0.85
Face + chest + ears average								
Reflective to no wall	1.03	0.99	0.99	0.83	0.93	0.77	0.75	0.90
Reflective to non-reflective	1.79	1.92	1.47	1.44	1.34	1.18	1.47	1.52
Non-reflective to no wall	0.58	0.51	0.68	0.58	0.70	0.66	0.51	0.60
Facial features (only) average								
Reflective to no wall	0.96	1.02	1.03	0.85	1.02	0.76	0.73	0.91
Reflective to non-reflective	1.91	2.26	1.47	1.44	1.46	1.15	1.53	1.60
Non-reflective to no wall	0.50	0.45	0.70	.059	0.70	0.66	0.48	0.58
Zinc aluminium trapezoidal								
All features average								
Reflective to no wall	1.05	1.20	1.24	1.04	1.01	0.98	0.88	1.06
Reflective to non-reflective	1.39	1.21	1.18	1.24	1.15	1.12	0.96	1.18
Non-reflective to no wall	0.76	0.99	1.05	0.84	0.88	0.87	0.92	0.90
Face + chest + ears average								
Reflective to no wall	1.18	1.08	1.22	0.94	0.87	1.02	0.92	1.03
Reflective to non-reflective	2.17	1.93	1.63	1.68	1.54	1.16	1.04	1.59
Non-reflective to no wall	0.54	0.56	0.75	0.56	0.57	0.88	0.88	0.68
Facial features (only) average								
Reflective to no wall	1.21	1.06	1.31	0.95	0.91	1.08	0.87	1.05
Reflective to non-reflective	2.63	2.47	1.69	1.79	1.59	1.23	0.98	1.77
Non-reflective to no wall	0.46	0.43	0.77	0.53	0.57	0.88	0.88	0.65

3.3.4 Repeat of zinc aluminium trapezoidal Spring 2010

The erythemal exposure measurements repeated for zinc aluminium trapezoidal were made on 17 and 18 October 2010. The OMI ozone was recorded at 304 DU on 17 October but was not recorded on 18 October. The weather conditions were clear with low to no cloud on both days of measurement.

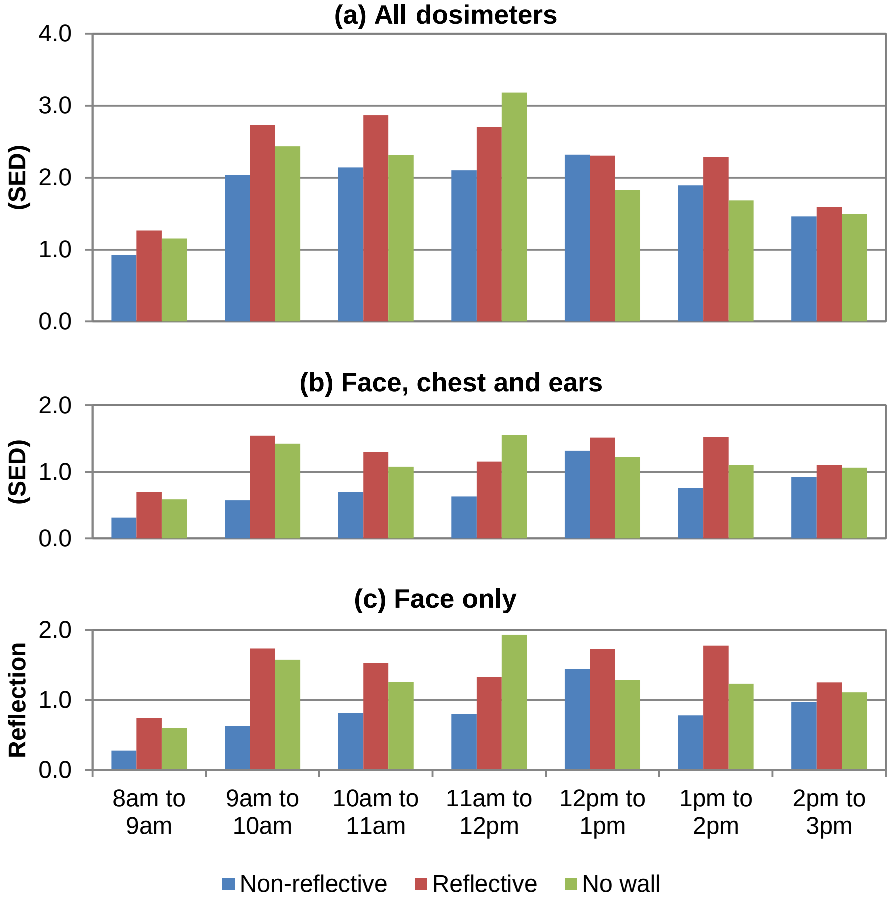

Figure 3.68 - Average erythemal exposure of three groups (consisting of thirteen, eight and five respectively) of dosimeters per head form over intervals of hourly measurement for zinc aluminium trapezoidal wall, a non-reflective wall and no wall in spring 2010.

Comparison of the exposures received by each wall type is tabulated in Table 3.6.

Table 3.6 – Ratios of average erythemal exposure received for head forms located near zinc aluminium trapezoidal reflective, non-reflective and no wall for different dosimeter groupings, Spring 2010.

	8 am to 9 am	9 am to 10 am	10 am to 11 am	11 am to 12 pm	12 pm to 1 pm	1 pm to 2 pm	2 pm to 3 pm	Daily average
Zinc Aluminium Trapezoidal								
All features average								
Reflective to no wall	1.10	1.12	1.24	0.85	1.26	1.36	1.06	1.14
Reflective to non-reflective	1.37	1.34	1.34	1.29	0.99	1.09	1.09	1.23
Non-reflective to no wall	0.80	0.84	0.93	0.66	1.27	0.98	0.98	0.94
Face + chest + ears average								
Reflective to no wall	1.19	1.08	1.21	0.74	1.24	1.38	1.04	1.13
Reflective to non-reflective	2.23	2.70	1.86	1.82	1.15	2.01	1.19	1.85
Non-reflective to no wall	0.53	0.40	0.65	0.41	1.08	0.69	0.87	0.66
Facial features (only) average								
Reflective to no wall	1.24	1.10	1.22	0.69	1.35	1.44	1.13	1.17
Reflective to non-reflective	2.71	2.76	1.88	1.66	1.20	2.28	1.29	1.97
Non-reflective to no wall	0.46	0.40	0.64	0.41	1.12	0.63	0.88	0.65

3.3.5 Quantification of biological effect of UV exposure due to vertical, inclined or horizontal UV reflective surfaces

The influence of differently oriented surfaces on personal erythemal exposure was investigated for two types of metal sheeting, zinc aluminium trapezoidal and pale green paint coated trapezoidal. Three surfaces were oriented north at various orientations: inclined at 35° to the horizontal, vertically and horizontally. Head forms were positioned as if a person may be working over these particular surfaces. Therefore, a head form was oriented parallel to the surface in question at approximately an arm’s length from the surface.

3.3.5.1 Zinc aluminium trapezoidal

3.3.5.1.1 North facing surfaces

The measurements for exposure due to inclined, vertical and horizontal surfaces oriented towards north for zinc aluminium trapezoidal, were measured over three days; 3, 4 and 5 March 2009. Ozone was measured at 249 DU on 4 March, 2009 however the OMI recorded ozone was not available for either of the other days. The erythemal exposure data is presented in Figure 3.69.

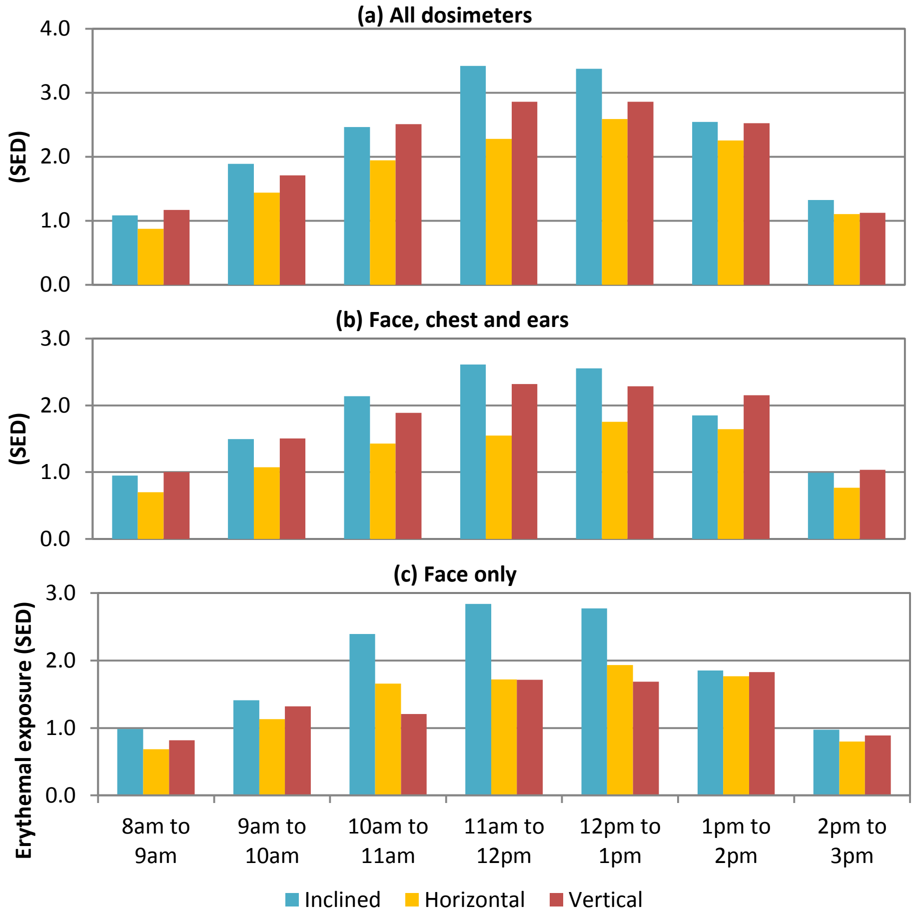

Figure 3.69 - Average erythemal reflection of three groups (consisting of thirteen, eight and five respectively) of dosimeters per head form for zinc aluminium trapezoidal north facing walls oriented to the vertical, inclined and horizontal over hourly intervals.

3.3.5.1.2 East and west facing surfaces

The measurements for exposure due to inclined, vertical and horizontal zinc aluminium trapezoidal surfaces oriented towards the east (before noon) and the west (after noon) were measured over two days, 17 and 23 March 2009. OMI ozone was recorded at 258 DU on 17 March and 264 DU on 23 March. The erythemal exposure data is presented in Figure 3.70.

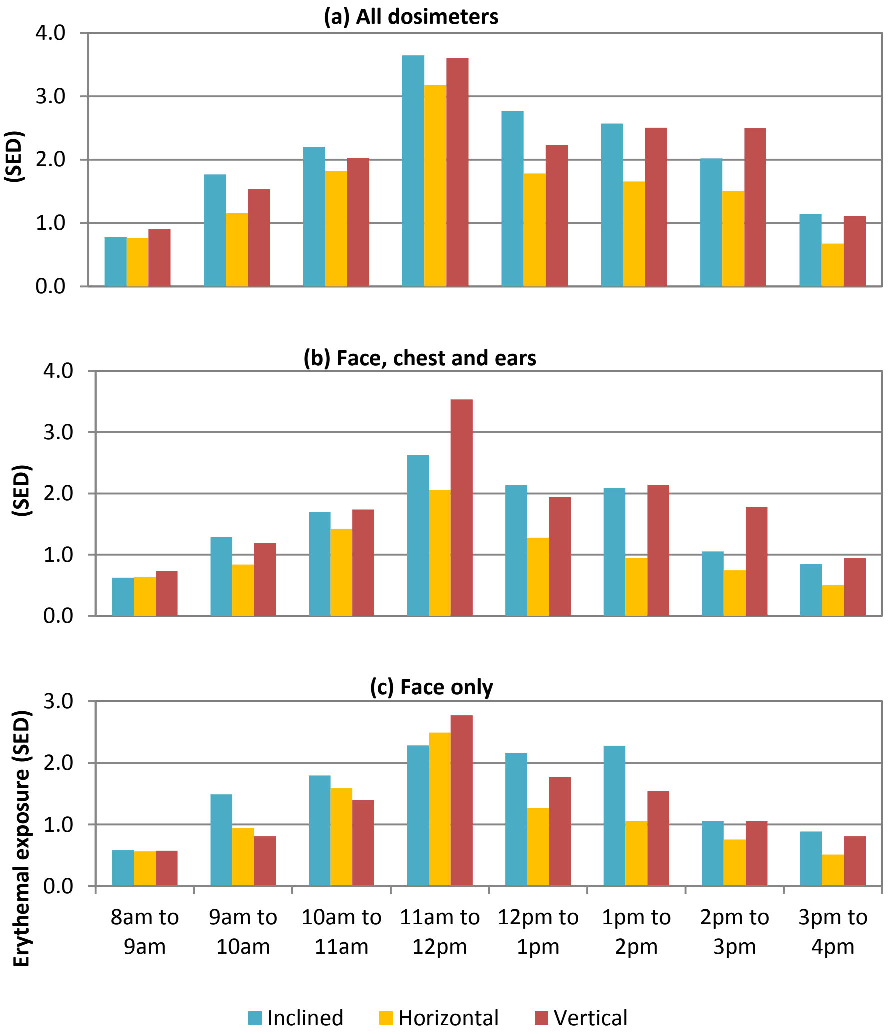

Figure 3.70 – Average erythemal reflection of three groups (consisting of thirteen, eight and five respectively) of dosimeters per head form for zinc aluminium trapezoidal walls oriented to the vertical, inclined and horizontal (east facing before noon and west facing after noon) over hourly intervals.

3.3.5.2 Pale green trapezoidal

The erythemal exposure measurements due to inclined, vertical and horizontal pale green trapezoidal surfaces oriented towards the north were measured on 28 and 29 April, 2009 and is shown in Figure 3.71. Ozone was measured at 258 DU on 28 April but was not recorded on 29 April.

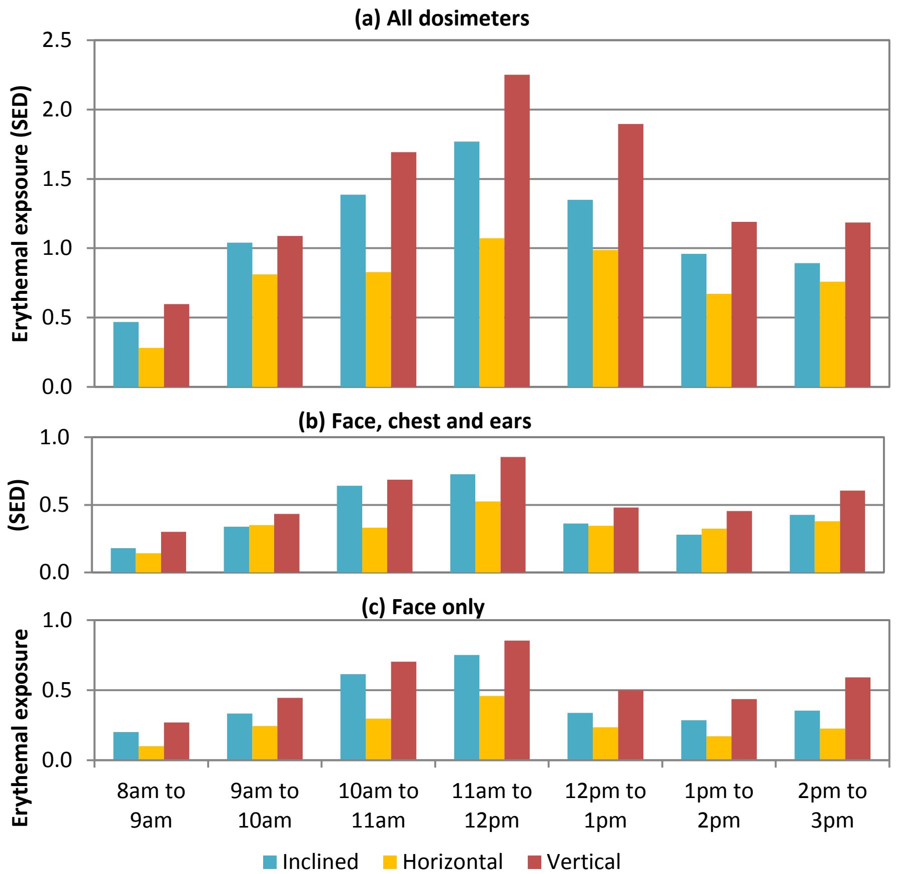

Figure 3.71 - Average erythemal reflection of three groups (consisting of thirteen, eight and five respectively) of dosimeters per head form for pale green trapezoidal north facing walls oriented to the vertical, inclined and horizontal over hourly intervals.

3.3.5.3 Comparison between surface types and orientations

A comparison between the exposures recorded for each head form orientation for the different surface types and directions was calculated using a ratio similar to the previous measurements for vertical surfaces only. The data is presented in Table 3.7.

Table 3.7 - Comparison of the ratios of average erythemal exposure received for head forms located near vertical reflective, inclined reflective and horizontal reflective surfaces, for different dosimeter groupings for early Autumn 2009.

	8 am to 9 am	9 am to 10 am	10 am to 11 am	11 am to 12 pm	12 pm to 1 pm	1 pm to 2 pm	2 pm to 3 pm	3 pm to 4 pm	Daily average
Zinc Aluminium trapezoidal (north facing)									
All features average									
Inclined to horizontal	1.24	1.31	1.27	1.50	1.30	1.13	1.20	-	1.28
Vertical to horizontal	1.33	1.19	1.29	1.25	1.11	1.12	1.02	-	1.19
Vertical to inclined	1.08	0.90	1.02	0.84	0.85	0.99	0.85	-	0.93
Face + chest + ears average									
Inclined to horizontal	1.36	1.39	1.50	1.69	1.46	1.13	1.29	-	1.40
Vertical to horizontal	1.44	1.40	1.32	1.50	1.30	1.31	1.35	-	1.37
Vertical to inclined	1.06	1.01	0.88	0.89	0.89	1.16	1.04	-	0.99
Facial features (only) average									
Inclined to horizontal	1.02	1.53	1.21	1.15	1.55	1.55	1.34	-	1.33
Vertical to horizontal	1.19	1.17	0.73	1.00	0.87	1.03	1.11	-	1.01
Vertical to inclined	0.83	0.93	0.50	0.60	0.61	0.99	0.91	-	0.77
Zinc aluminium trapezoidal (east and west facing)									
All features average									
Inclined to horizontal	1.02	1.53	1.21	1.15	1.55	1.55	1.34	1.68	1.38
Vertical to horizontal	1.19	1.33	1.11	1.14	1.25	1.51	1.65	1.64	1.35
Vertical to inclined	1.16	0.87	0.92	0.99	0.81	0.98	1.24	0.97	0.99
Face + chest + ears average									
Inclined to horizontal	0.98	1.53	1.19	1.28	1.68	2.22	1.42	1.67	1.50
Vertical to horizontal	1.16	1.42	1.22	1.72	1.52	2.27	2.39	1.87	1.70
Vertical to inclined	1.18	0.93	1.02	1.35	0.91	1.02	1.69	1.12	1.15
Facial features (only) average									
Inclined to horizontal	1.03	1.58	1.13	0.92	1.71	2.16	1.39	1.73	1.46
Vertical to horizontal	1.01	0.86	0.88	1.11	1.40	1.46	1.39	1.58	1.21
Vertical to inclined	0.98	0.54	0.78	1.22	0.82	0.68	1.00	0.91	0.87
Pale green trapezoidal (north facing)									
All features average									
Inclined to horizontal	1.67	1.28	1.67	1.65	1.37	1.43	1.18	-	1.46
Vertical to horizontal	2.13	1.34	2.05	2.10	1.92	1.78	1.56	-	1.84
Vertical to inclined	1.27	1.05	1.22	1.27	1.41	1.24	1.33	-	1.26
Face + chest + ears average									
Inclined to horizontal	1.25	0.97	1.93	1.38	1.05	0.87	1.12	-	1.22
Vertical to horizontal	2.09	1.24	2.06	1.63	1.39	1.40	1.60	-	1.63
Vertical to inclined	1.67	1.28	1.07	1.18	1.32	1.62	1.42	-	1.36
Facial features (only) average									
Inclined to horizontal	1.98	1.36	2.07	1.64	1.45	1.67	1.58	-	1.68
Vertical to horizontal	2.68	1.82	2.37	1.87	2.14	2.57	2.63	-	2.30
Vertical to inclined	1.35	1.33	1.15	1.14	1.47	1.54	1.67	-	1.38

3.3.6 Quantification of biological effect on UV exposure due to UV reflective surfaces positioned at vertical vertices.

3.3.6.1 Zinc aluminium trapezoidal

The erythemal exposure measurements made for a zinc aluminium trapezoidal corner were made over three days on 26 March and 15 and 16 April 2009. The ozone values recorded were 255 DU, 266 DU and 265 DU respectively. The data is presented in Figure 3.72.

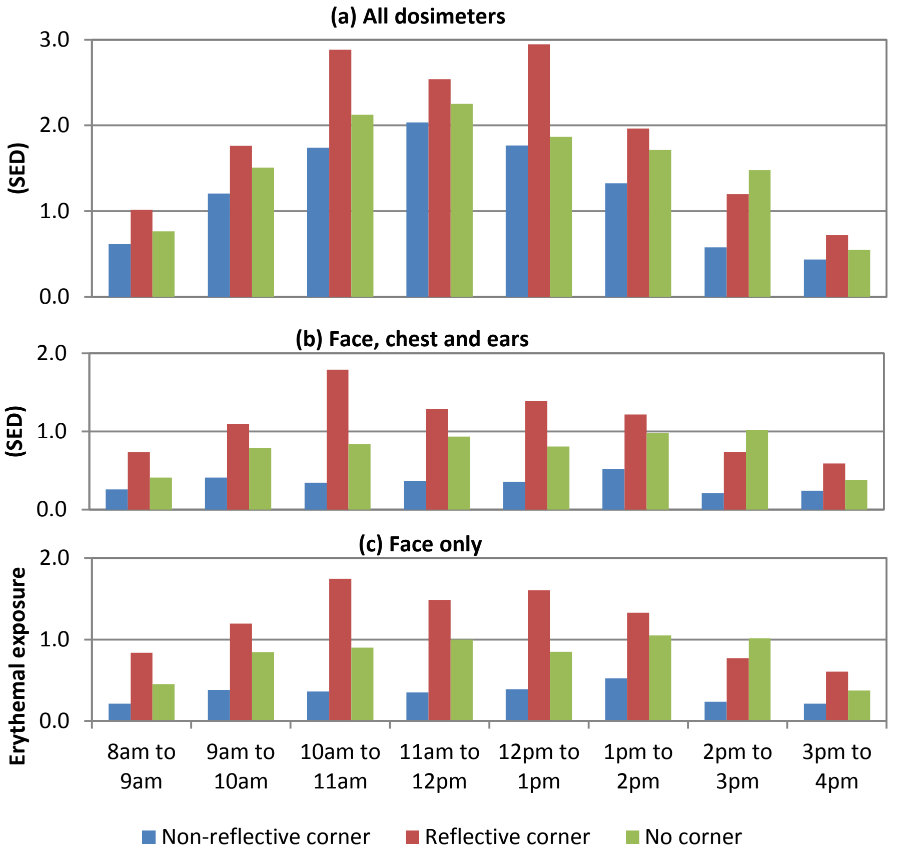

Figure 3.72 – Average erythemal exposure of three groups (consisting of thirteen, eight and five respectively) of dosimeters per head form for zinc aluminium trapezoidal corner, non-reflective corner and no corner for hourly intervals.

3.3.6.2 Pale green trapezoidal

The erythemal exposure measurements made for a pale green trapezoidal corner were made over two days on 22 and 23 April 2009. The ozone value recorded for 23 April was 265 DU but no measurement was recorded on 22 April. The data is presented in Figure 3.73.

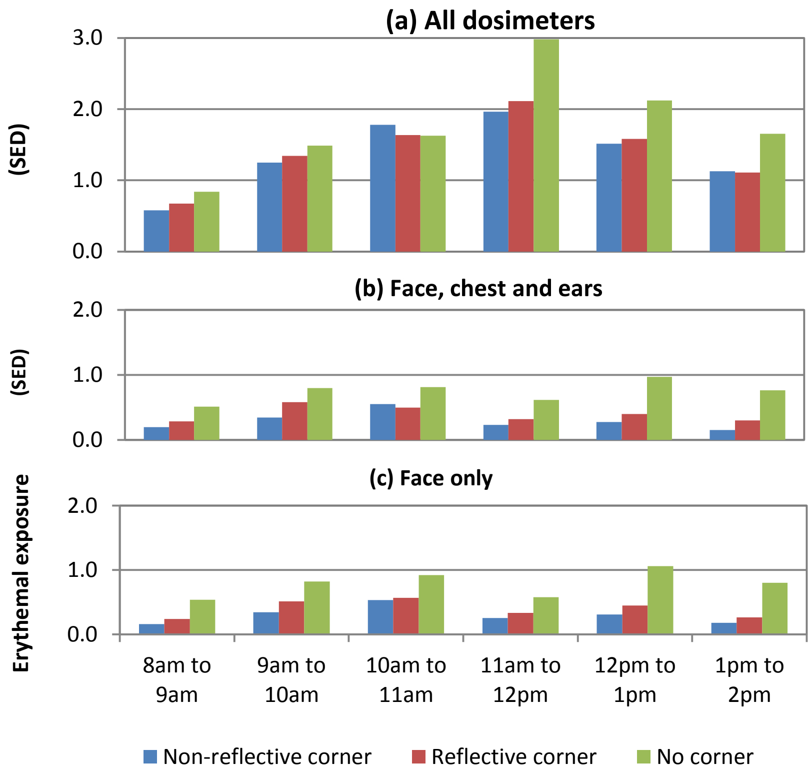

Figure 3.73 - Average erythemal exposure of three groups (consisting of thirteen, eight and five respectively) of dosimeters per head form for pale green trapezoidal corner, non-reflective corner and no corner for hourly intervals.

3.3.6.3 Comparison between surface types

A comparison between the erythemal exposures received for zinc aluminium trapezoidal and pale green trapezoidal corners is expressed using the ratios shown in the first column and is tabulated in Table 3.8.

Table 3.8 - Comparison of the ratios of average erythemal exposure received for head forms located near reflective vertical vertices, non-reflective and no vertices for different dosimeter groupings for Autumn 2009.

	8 am to 9 am	9 am to 10 am	10 am to 11 am	11 am to 12 pm	12 pm to 1 pm	1 pm to 2 pm	2 pm to 3 pm	3 pm to 4 pm	Daily average
Zinc Aluminium trapezoidal									
All features average									
Reflective to no wall	1.33	1.17	1.36	1.13	1.58	1.15	0.81	1.31	1.23
Reflective to non-reflective	1.64	1.46	1.66	1.25	1.67	1.48	2.06	1.65	1.61
Non-reflective to no wall	0.81	0.80	0.82	0.90	0.95	0.78	0.39	0.80	0.78
Face + chest + ears average									
Reflective to no wall	1.78	1.39	2.14	1.37	1.72	1.24	0.72	1.55	1.49
Reflective to non-reflective	2.84	2.68	5.16	3.48	3.89	2.33	3.52	2.41	3.29
Non-reflective to no wall	0.63	0.52	0.41	0.39	0.44	0.53	0.21	0.64	0.47
Facial features (only) average									
Reflective to no wall	1.85	1.42	1.94	1.49	1.89	1.27	0.76	1.61	1.53
Reflective to non-reflective	3.93	3.15	4.82	4.23	4.11	2.54	3.26	2.84	3.61
Non-reflective to no wall	0.47	0.45	0.40	0.35	0.46	0.50	0.23	0.57	0.43

Pale green trapezoidal

All features average									
Reflective to no wall	0.80	0.90	1.01	0.71	0.75	0.67	-	-	0.81
Reflective to non-reflective	1.16	1.07	0.92	1.08	1.04	0.98	-	-	1.04
Non-reflective to no wall	0.69	0.84	1.09	0.66	0.71	0.68	-	-	0.78
Face + chest + ears average									
Reflective to no wall	0.55	0.73	0.61	0.52	0.41	0.39	-	-	0.54
Reflective to non-reflective	1.44	1.71	0.91	1.39	1.45	1.98	-	-	1.48
Non-reflective to no wall	0.38	0.43	0.67	0.37	0.28	0.20	-	-	0.39
Facial features (only) average									
Reflective to no wall	0.44	0.62	0.61	0.58	0.42	0.33	-	-	0.50
Reflective to non-reflective	1.47	1.49	1.07	1.30	1.44	1.48	-	-	1.38
Non-reflective to no wall	0.30	0.42	0.58	0.44	0.29	0.22	-	-	0.38

Figure 3.74 compares the ratio of exposures received by a zinc aluminium trapezoidal wall and corner. Figure 3.75 compares the average daily ratio of exposures per individual dosimeter position on a head form. Figure 3.76 compares the ratio of exposures received by a pale green trapezoidal wall and corner.

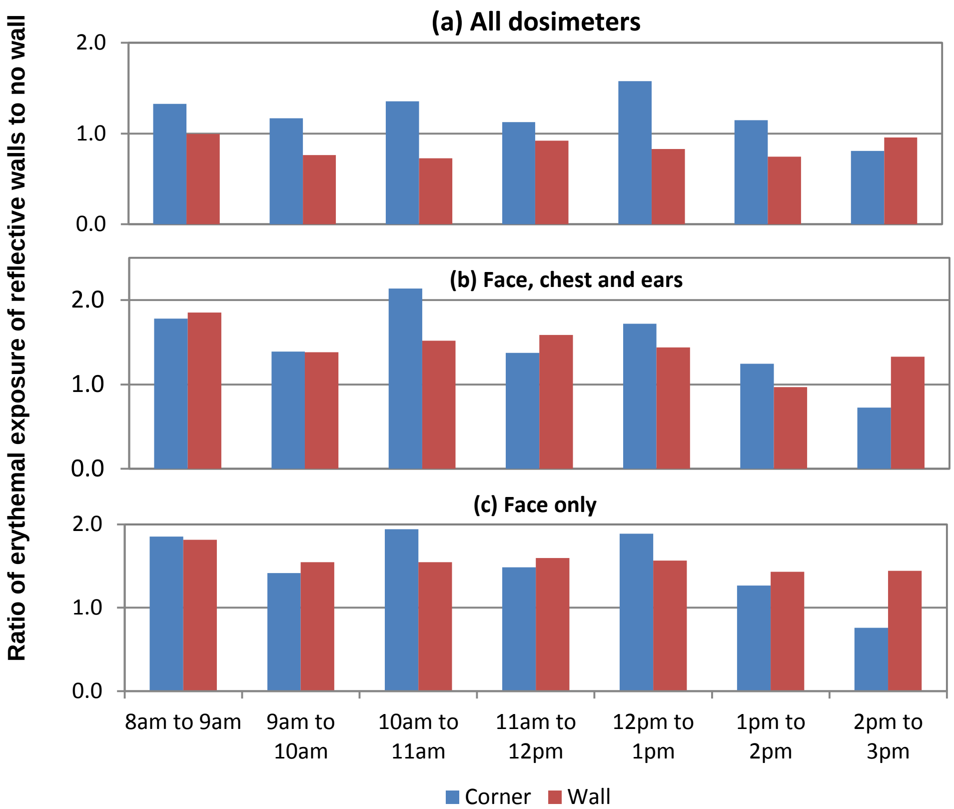

Figure 3.74 - Comparison between relative average erythemal exposures of three groups (consisting of thirteen, eight and five respectively) measured for a corner (vertice) measured in Autumn 2008 and a wall in Autumn 2009 for zinc aluminium trapezoidal over hourly intervals.

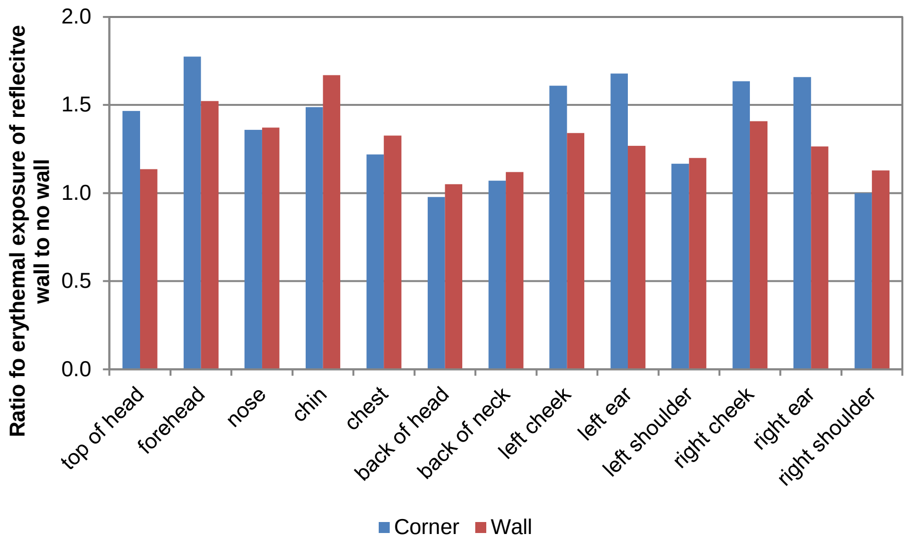

Figure 3.75 – Average daily ratio of erythemal exposure due to a reflective wall compared to no wall for individual dosimeter positions on a head form, for a zinc aluminium trapezoidal wall (Autumn 2008) and corner (Autumn 2009).

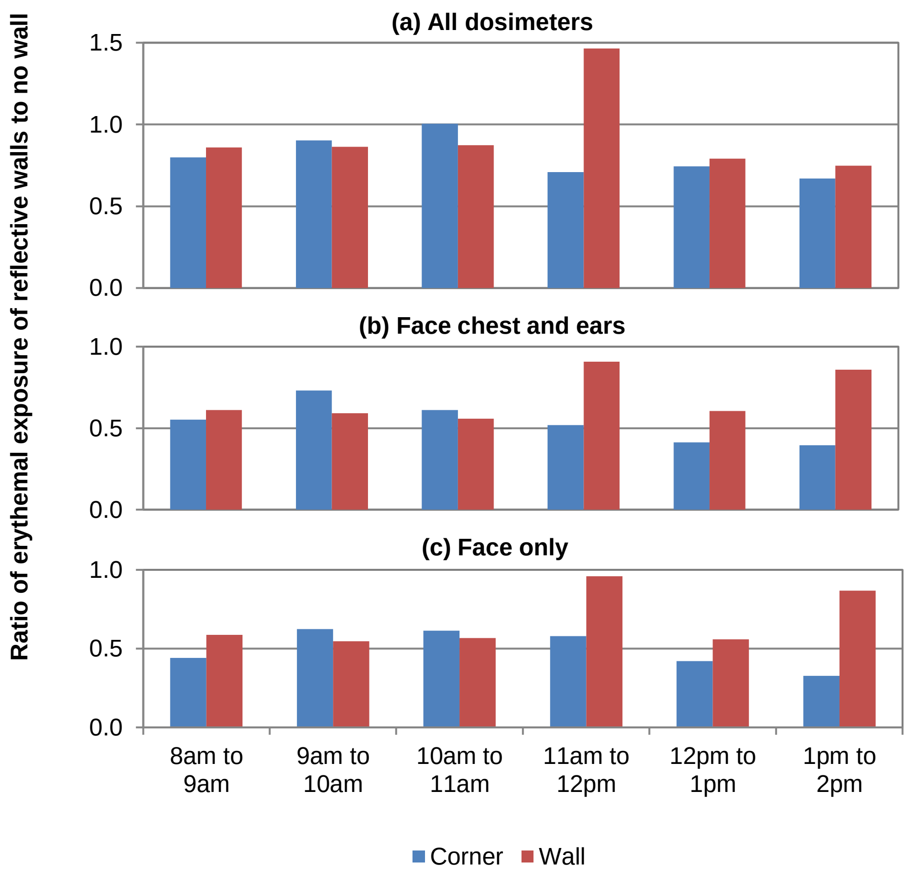

Figure 3.76 - Comparison between relative average erythemal exposures of three groups (consisting of thirteen, eight and five respectively) measured for a corner (vertice) in Autumn 2008 and a wall in Autumn 2009 for pale green trapezoidal over hourly intervals.

3.3.7 Quantification of biological effect on UV exposure due to non-metallic UV reflecting surfaces

3.3.7.1 White painted fibro board

The erythemal exposure measurements made for white painted fibro board were made over two days on 5 and 15 May 2009. The wall was part of a building located on the campus of the University of Southern Queensland with no surrounding gardens and supported by metal stumps. The head forms were supported by the frames used in the vertical, horizontal and inclined wall measurements and lifted off the ground with crates. The ozone value recorded for 5 May was 257 DU but no measurement was recorded on 15 May. There was low to no clouds initially on 5 May, but reached up to 40% coverage by the afternoon. There were no clouds on 15 May. The data is presented in Figure 3.77.

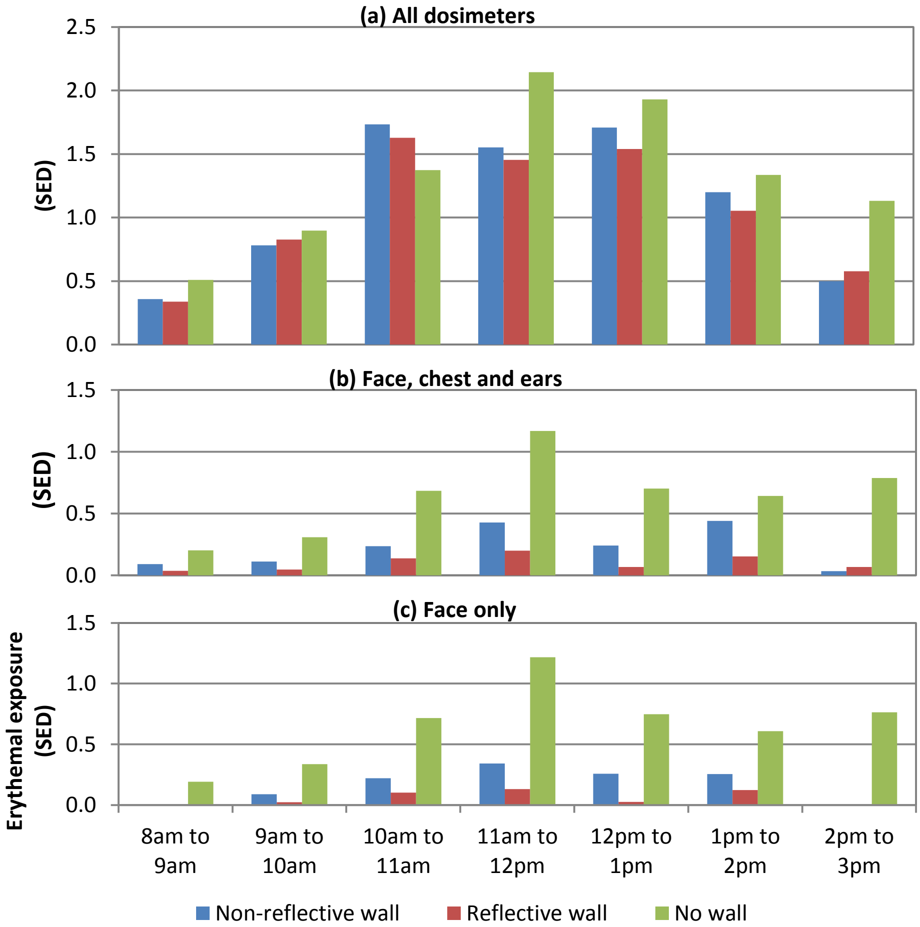

Figure 3.77 - Average erythemal exposure of three groups (consisting of thirteen, eight and five respectively) dosimeters per head form for white painted fibro board wall, non-reflective wall and no wall over hourly intervals.

3.3.7.2 Red brick

The erythemal exposure measurements made for red brick were made over two days on 8 and 9 June 2009. The wall was part of a building located on the campus of the University of Southern Queensland with no surrounding gardens but a concreted pathway. The ozone value recorded for 8 June was 267 DU but no measurement was recorded on 9 June. The weather conditions included less than 10% cloud cover on 8 June, but up to 40% cloud cover on 9 June throughout the day. The data is presented in Figure 3.78.

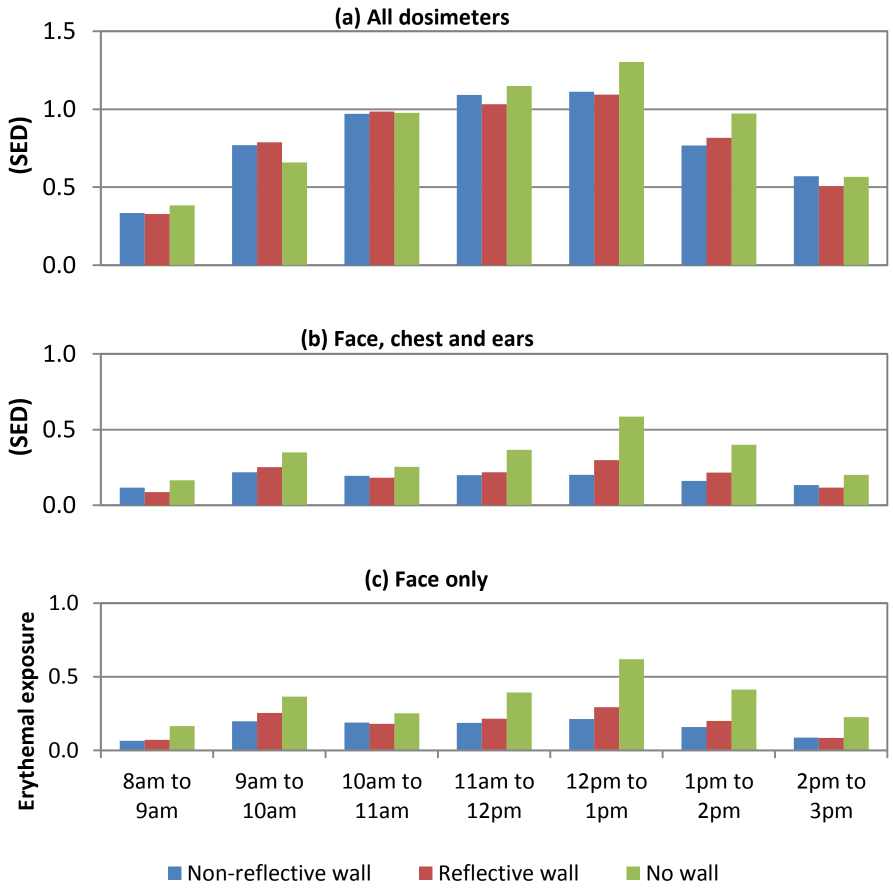

Figure 3.78 - Average erythemal exposure of three groups (consisting of thirteen, eight and five respectively) dosimeters per head form for red brick wall, non-reflective wall and no wall over hourly intervals.

3.3.7.3 Comparison between surfaces

A comparison of the ratios of the exposures for red brick and white painted fibro board is presented in Table 3.9.

Table 3.9 - Comparison of the ratios of average erythemal exposure received for head forms located near non-metallic reflective walls, non-reflective and no wall for different dosimeter groupings for Autumn and Winter 2009.

	8 am to 9 am	9 am to 10 am	10 am to 11 am	11 am to 12 pm	12 pm to 1 pm	1 pm to 2 pm	2 pm to 3 pm	Daily average
White painted fibro board								
All features average								
Reflective to no wall	0.66	0.92	1.18	0.68	0.80	0.79	0.51	0.79
Reflective to non-reflective	0.95	1.06	0.94	0.94	0.90	0.88	1.16	0.97
Non-reflective to no wall	0.70	0.87	1.26	1.26	0.89	0.90	0.44	0.83
Face + chest + ears average								
Reflective to no wall	0.17	0.15	0.20	0.17	0.10	0.24	0.08	0.16
Reflective to non-reflective	0.38	0.41	0.58	0.47	0.28	0.35	2.02	0.64
Non-reflective to no wall	0.45	0.36	0.35	0.37	0.34	0.68	0.04	0.37
Facial features (only) average								
Reflective to no wall	0	0.07	0.14	0.11	0.04	0.20	0	0.08
Reflective to non-reflective	0	0.26	0.46	0.39	0.10	0.49	0	0.28
Non-reflective to no wall	0	0.26	0.31	0.28	0.34	0.42	0	0.23
Red brick								
All features average								
Reflective to no wall	0.85	1.20	1.01	0.90	0.84	0.84	0.89	0.93
Reflective to non-reflective	0.98	1.02	1.02	0.95	0.98	1.06	0.89	0.99
Non-reflective to no wall	0.87	1.17	0.99	0.95	0.85	0.79	1.01	0.95
Face + chest + ears average								
Reflective to no wall	0.52	0.72	0.67	0.65	0.60	0.59	0.59	0.61
Reflective to non-reflective	0.75	1.16	0.99	1.02	1.12	1.15	1.12	1.02
Non-reflective to no wall	0.70	0.62	0.68	0.64	0.54	0.51	0.52	0.61
Facial features (only) average								
Reflective to no wall	0.44	0.69	0.72	0.55	0.47	0.49	0.37	0.53
Reflective to non-reflective	1.11	1.28	0.96	1.15	1.39	1.26	0.97	1.16
Non-reflective to no wall	0.39	0.54	0.75	0.48	0.34	0.39	0.39	0.47

3.4 Quantification of relationship between horizontal and vertical reflectivity

3.4.1 Zinc aluminium trapezoidal

At the same time as many of the UV exposure measurements, the spectral reflection was also measured. This measurement has been converted to an erythemal reflection ratio (as previously discussed). For the exposure measurements comparing orientation of the surface, the corresponding erythemal reflection ratios can be used to determine a possible relationship between a vertical, inclined or horizontal reflection since each measurement for each surface orientation was made at the same SZA and SAA. Figure 3.79 compares the reflection values between vertical and horizontal erythemal reflection ratios for zinc aluminium trapezoidal and Figure 3.80 compares the erythemal reflection ratios for vertical and inclined surfaces. The figures are separated into two plots, one that uses all the data for all SZA and has a line of best fit, and the second which separates the data into different grouped SZA ranges. The ranges used are arbitrary groupings.

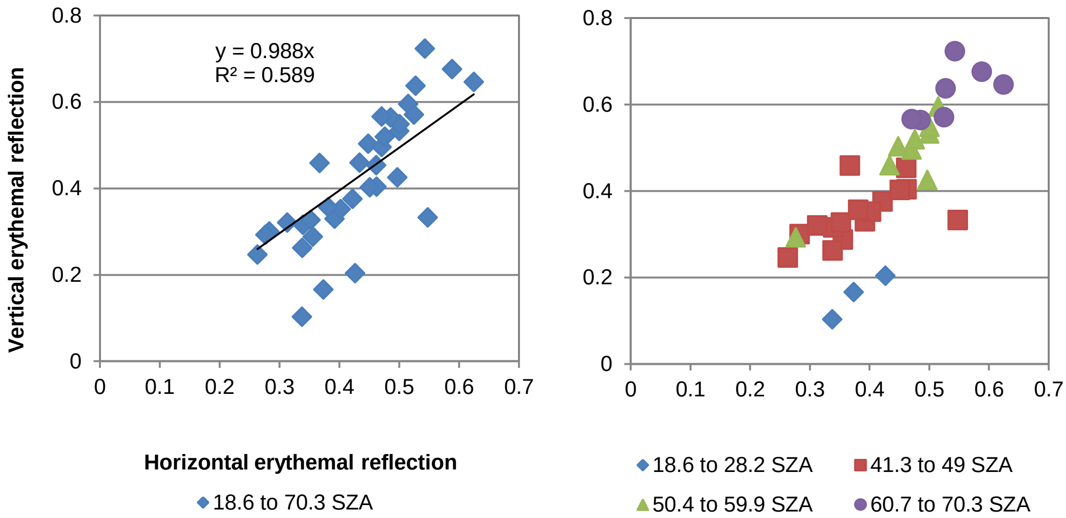

Figure 3.79 – Vertical erythemal reflection compared to horizontal erythemal reflection for same SZA and SAA for each pair of vertical and horizontal erythemal reflection values for zinc aluminium trapezoidal.

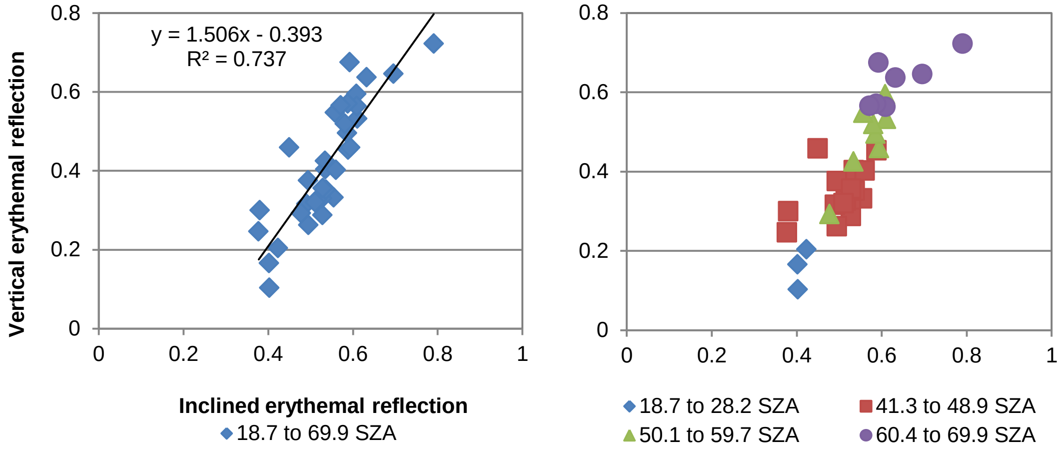

Figure 3.80 - Vertical erythemal reflection compared to inclined erythemal reflection for same SZA and SAA for each pair of vertical and inclined erythemal reflection values for zinc aluminium trapezoidal.

3.4.2 Pale green trapezoidal

Figure 3.81 compares the reflection values between vertical and horizontal erythemal reflection ratios for pale green trapezoidal and Figure 3.82 compares the erythemal reflection ratios for vertical and inclined surfaces. The treatments used in the zinc aluminium trapezoidal analysis have also been used here.

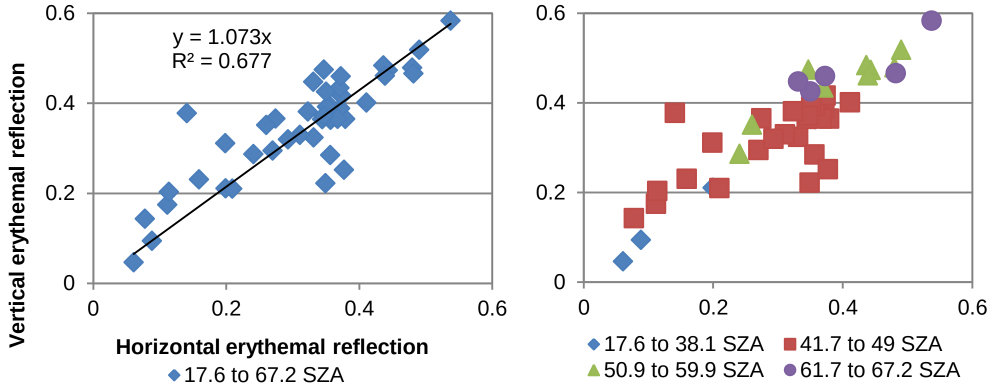

Figure 3.81 – Vertical erythemal reflection compared to horizontal erythemal reflection for same SZA and SAA for each pair of vertical and horizontal erythemal reflection values for pale green trapezoidal.

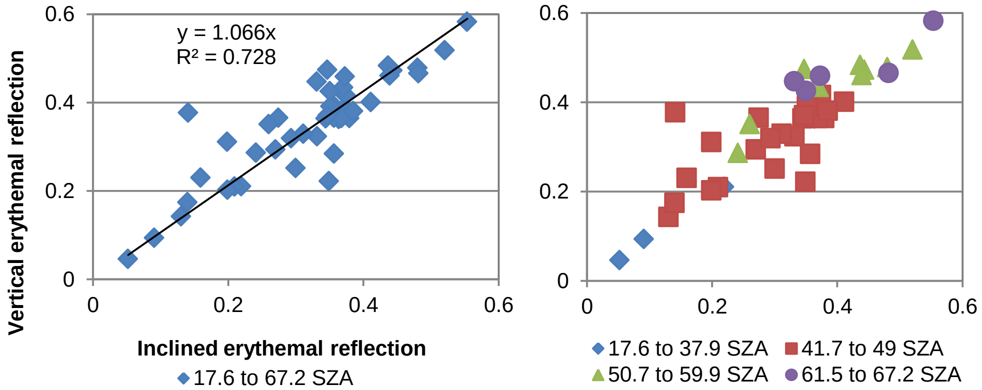

Figure 3.82 - Vertical erythemal reflection compared to inclined erythemal reflection for same SZA and SAA for each pair of vertical and inclined erythemal reflection values for pale green trapezoidal.

3.5 Establishing a UVI factor for UV reflective surfaces

The measured erythemal UV exposure incurred due to a reflective wall, non-reflective wall and no wall were plotted against the average hourly UV Index. The coefficient of the slope of the resulting linear trend lines for total average dosimeter exposure has been tabulated in Table 3.10 for all measurements made (charts located in Appendix 7.3). The data is then generalized in Table 3.11 for the same surface coating groups.

Table 3.10 – Tabulated data (coefficient values) from plots of erythemal exposure (all dosimeter average) vs. UVI hourly average. Values in brackets represent R^2.

Metal Type	Exposure coefficient from UVI for wall types (R^2) Reflective wall	Non-Reflective wall	No wall	Ratio Reflective wall to No wall
Zinc aluminium trapezoidal				
Autumn 2008	0.529	0.372	0.452	1.17
	(0.907)	(0.965)	(0.950)	
Spring 2008	0.356	0.303	0.333	1.07
	(0.870)	(0.803)	(0.787)	
Spring 2010	0.329	0.271	0.295	1.11
	(0.471)	(0.77)	(0.401)	
Autumn 2009	0.386	0.259	0.312	1.24
(corner)	(0.604)	(0.896)	(0.643)	
Zinc aluminium corrugated				
Early Spring 2008	0.343	0.325	0.272	1.26
	(0.884)	(0.845)	(0.762)	
Pale green trapezoidal				
Autumn 2008	0.134	0.105	0.183	0.73
	(0.521)	(0.418)	(0.367)	
Autumn 2009	0.306	0.299	0.391	0.78
(corner)	(0.643)	(0.732)	(0.658)	
Cream trapezoidal				
Autumn 2008	0.339	0.323	0.364	0.93
	(0.913)	(0.966)	(0.857)	
Winter 2008	0.335	0.318	0.374	0.90
	(0.599)	(0.767)	(0.77)	

Table 3.11 – Coefficient values from plots of erythemal exposure for different dosimeter groupings for all data from zinc aluminium coated surfaces and all paint coated surfaces (See Sections 7.3.5 and 7.3.6).

	Exposure coefficient from UVI for wall types (R^2)			
Metal Type	Reflective wall	Non-Reflective wall	No wall	Ratio Reflective wall to No wall
Zinc aluminium finish				
All dosimeters	0.348	0.283	0.311	1.12
	(0.788)	(0.822)	(0.782)	
Face chest and ears	0.208	0.11	0.181	1.15
	(0.253)	(0.326)	(0.432)	
Face only	0.235	0.118	0.201	1.17
	(0.48)	(0.41)	(0.545)	
Paint coated surface				
All dosimeters	0.332	0.315	0.385	0.86
	(0.688)	(0.817)	(0.833)	
Face chest and ears	0.111	0.090	0.177	0.63
	(-0.055)	(0.073)	(0.291)	
Face only	0.115	0.092	0.188	0.62
	(0.114)	(0.193)	(0.295)	

The relationship between erythemal exposure and the average hourly UVI for a general surface type has been plotted in Figure 3.83 (zinc aluminium coated surface) and Figure 3.84 (paint coated surface type). For each of the dosimeter groupings a function describing a line of best fit for the two variables has been determined.

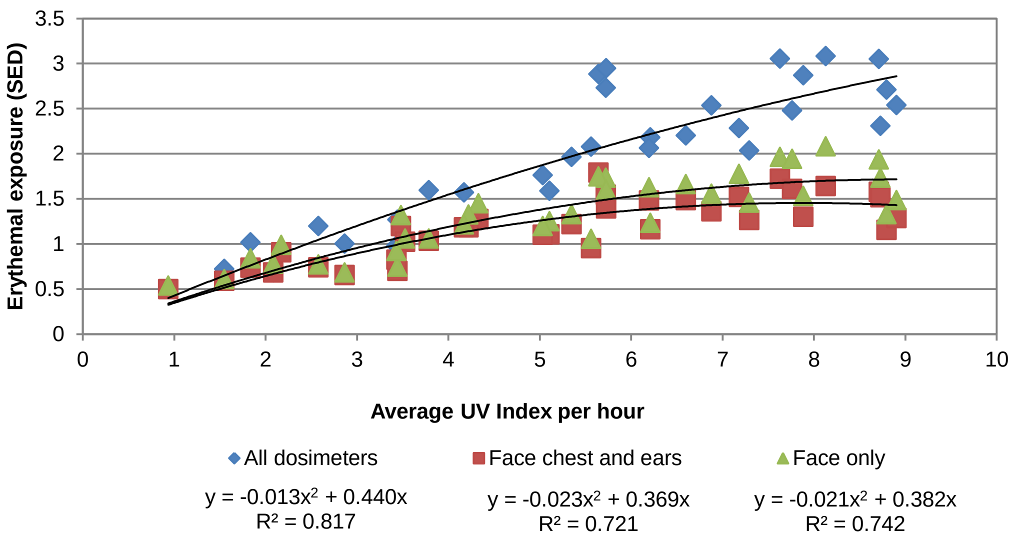

Figure 3.83 – Erythemal exposure (SED) correlated to average hourly UV Index for exposures influenced by zinc aluminium coated steel surfaces (trapezoidal and corrugated) for all over exposure to more specific exposures.

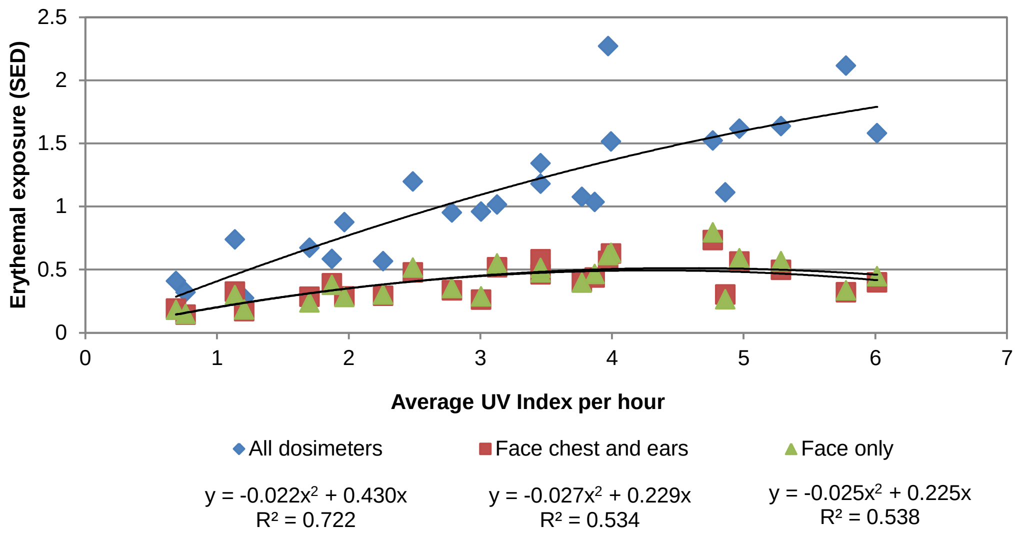

Figure 3.84 - Erythemal exposure (SED) correlated to average hourly UV Index for exposures influenced by paint coated steel surfaces (pale green and cream trapezoidal) for all over exposure to more specific exposures.

3.6 Resolving contributions of direct and diffuse UV radiation for effective reflectivity measurements

Diffuse reflection measurements were obtained on 19 October 2010. Most of this day had an unobscured sun, except during the middle of the day, when the sun was obscured for approximately an hour and a half by thick cloud. On this day all surface types were being measured, but the main surfaces used for diffuse reflection measurements were zinc aluminium trapezoidal and corrugated, and cream trapezoidal and corrugated. Further diffuse reflection measurements were carried out on some of the other paint coated surfaces, however the reflection measurements were very similar or the same as that found for cream coated surfaces. Therefore, only the cream coated surface measurements are presented here. Figure 3.85 shows the diffuse reflection measured for both corrugated surfaces, which are carried out by measuring the diffuse UV irradiance reflected from the surface and compared to the global UV irradiance measured (rather than total UV irradiance since the sun is obscured). The same has been done in Figure 3.86 for the trapezoidal surfaces.

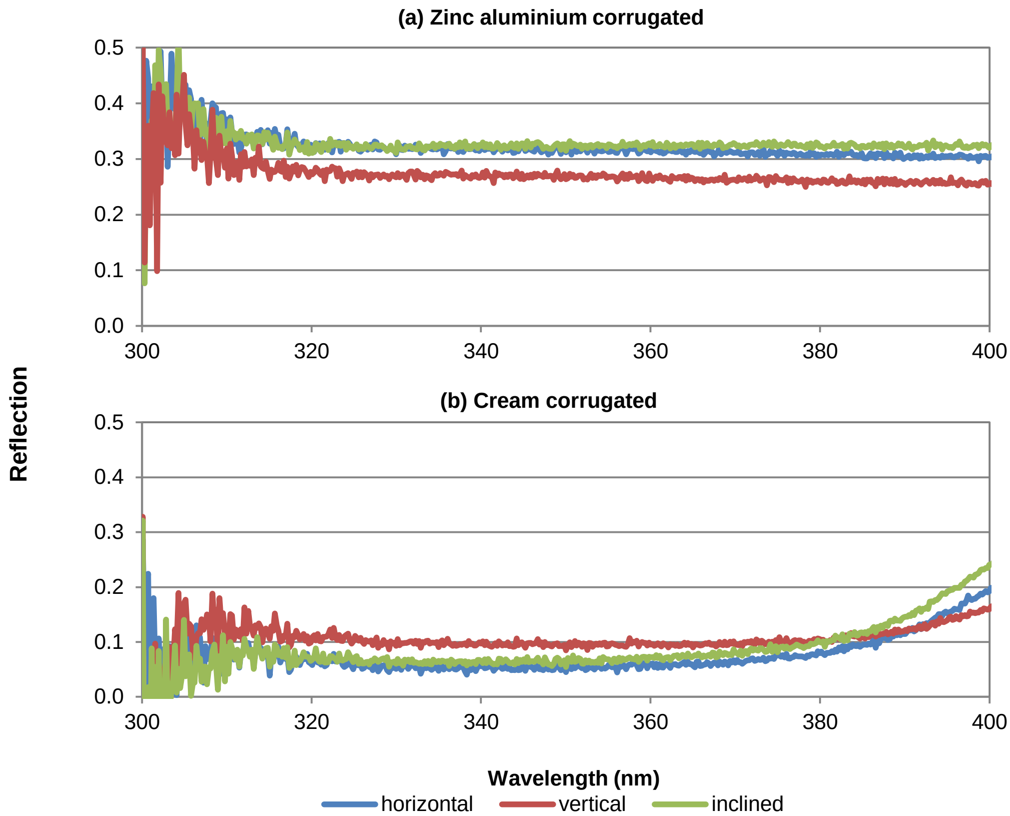

Figure 3.85 – Diffuse reflection from (a) zinc aluminium corrugated and (b) cream corrugated for horizontal, vertical and inclined surfaces.

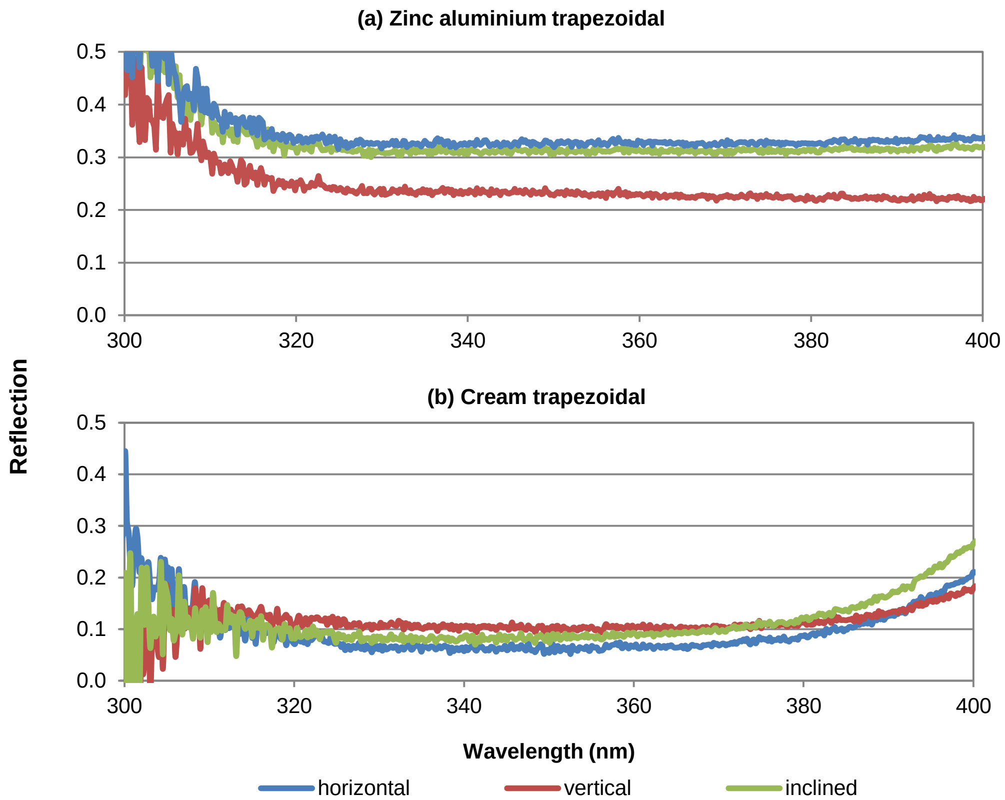

Figure 3.86 – Diffuse reflection from (a) zinc aluminium trapezoidal and (b) cream trapezoidal for horizontal, vertical and inclined surfaces.

Figure 3.87 compares the total reflection and diffuse reflection from zinc aluminium trapezoidal which was measured at the same SZA and SAA on two different days. Diffuse reflection appears to be larger than total reflection, however to put this into context Figure 3.88 presents the measured spectral UV irradiances used to calculate the spectral reflection.

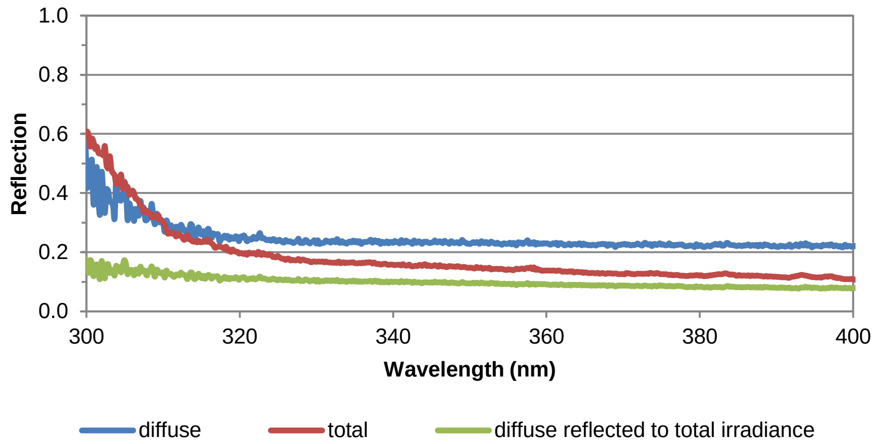

Figure 3.87 – Diffuse reflection (19 October 2010), total reflection (18 October 2010), and diffuse reflected UV irradiance relative to total UV irradiance comparison from zinc aluminium trapezoidal.

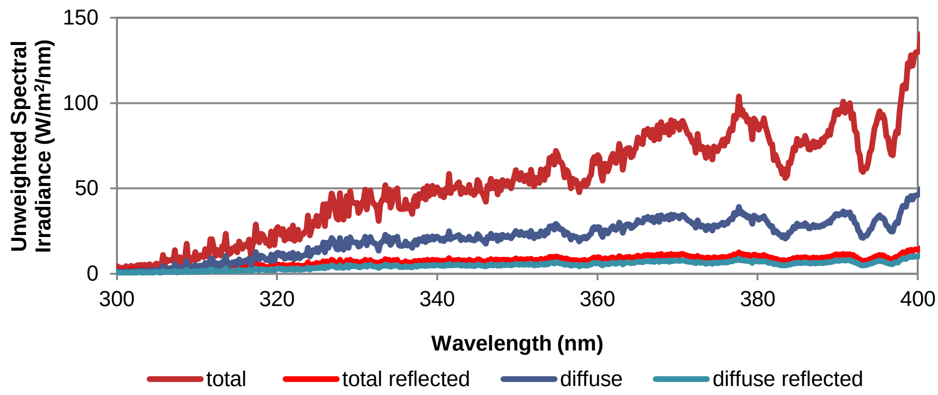

Figure 3.88 – Spectral irradiance measurements used to calculate the diffuse (19 October 2010) and direct (18 October 2010) spectral reflection in Figure 3.87.

To determine if the diffuse reflection measurements from a vertical surface were simply the same as standard diffuse irradiance measurements, measurements were taken under cloud obscured sun conditions with the sensor orientated to simulate measuring reflection from a vertical surface, but with no surface present. The two irradiance measurements were compared and presented in Figure 3.89 for the four different surface types used.

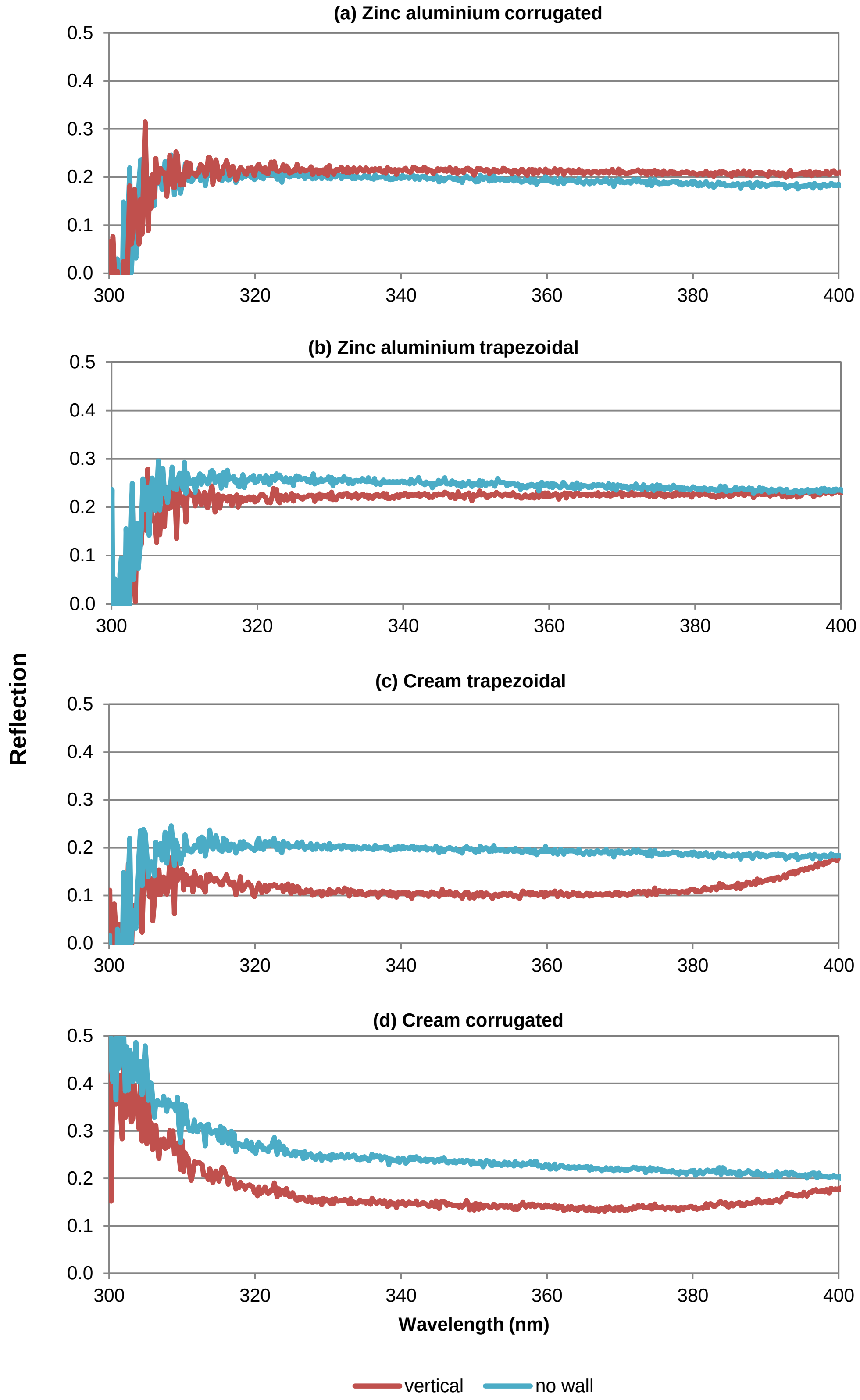

Figure 3.89 – Diffuse reflection ratio compared to ratio of: UV irradiance measured with sensor oriented in the same direction as a vertical wall sensor (but without a nearby wall) to global UV irradiance.

The position of sensor alignment to the surface was investigated briefly during other measurements. The galvanized surface (Section 3.2.4.1.1) was inclined at 5.1° from the horizontal with the inclined surface facing east. At a SZA of approximately 50° and SAA of approximately -60°, the sensor was inclined at 45° to the horizontal. The results of the measurements are given in Figure 3.90.

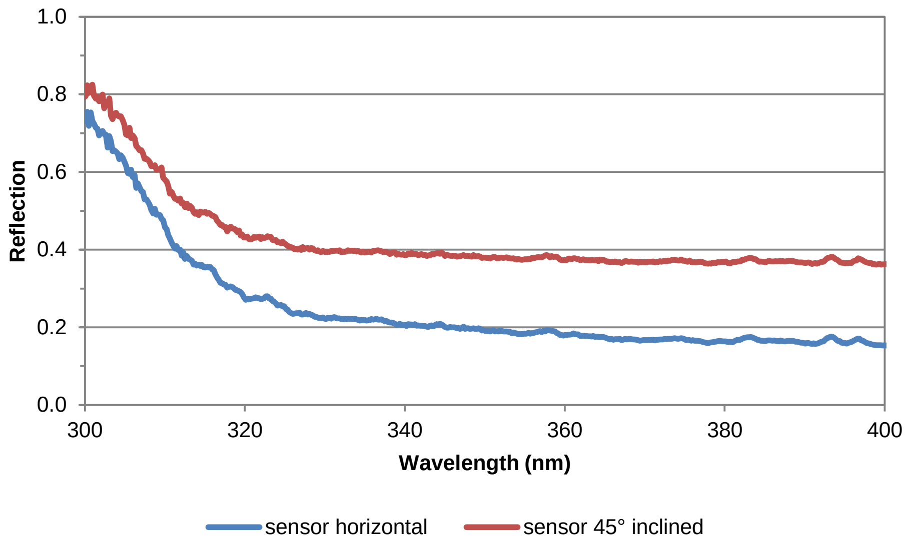

Figure 3.90 - Measurement of reflection from an inclined galvanised surface with sensor placed horizontally above the surface, and also placed 45° to the horizontal (SZA range 50° to 60°, SAA range -60° to -70°).

4 Discussion

The discussion has been broken down into sections similar to those presented in the previous chapters. Therefore the discussion will follow the same order as the presented results.

4.1 Overview

The literature review has explored the current knowledge of reflection from different surface types. This research was partially prompted by a preliminary study (Parisi 1999) and a later study on spectral albedo measurement (Lester & Parisi 2002). In both these studies, a spectroradiometer was used to measure the biologically effective UV radiation reflected from a surface compared to the biologically effective UV radiation measured on a horizontal surface. In the case of Parisi (1999) the reflected biologically effective UV was from vertical surfaces or walls compared to that on a horizontal surface and was found to have high reflectivity compared to that of natural surface reflection. Throughout this discussion, the technique itself of measuring reflection from a vertical surface will be explored. This technique required further development and refining in this project to produce data that can be compared to reflection from other surfaces. The overall influence of reflected UV radiation from vertical surfaces is discussed in relation to exposure on a human shape. The research objectives are addressed and the physical behaviour of UV radiation undergoing reflection is explored.

4.2 Quantification of UV reflection from metal surfaces due to multiple factors

The methodology outlines the strategies involved in obtaining the collected results.

4.2.1 Preliminary spectral reflection measurements

When exploring the reflective capabilities of a surface, it is important that the repeatability of the measurement is consistent. In the literature review it was found that currently accepted albedo values for different surfaces have little consistency, with information about sensor height or distance from a reflective surface limited and measurements encompassing different times of day even more limited. Most surfaces were assumed to be a Lambertian surface and isotropic, discounting the need to account for direction as the surface reflects equally in all directions. Unless shaded, a horizontal surface will be exposed to all radiation incident on the surface and therefore the previous assumption will be true. However, if the assumption is not true (the surface is anisotropic and non-Lambertian) then the reflection will not be reflected equally in all directions. In the case of metal surfaces, this last statement is likely to be true.

Vertical surfaces have the additional influencing factor of the position of the vertical surface, and what direction this surface is oriented to. Prior to beginning measurements to account for these different factors one additional factor was investigated and this was the shape of the reflecting surface itself. The two most common (although not limited to) types of metal sheeting profiles are corrugated and trapezoidal. The dimensions of the sheeting profiles have been given in the Methodology. Of the two profiles, corrugated has an even profile uniform across its width. Trapezoidal has larger flat areas compared to the ridged areas. Since most types of sheeting obtained were trapezoidal, it was important to know if the placement of the sensor over the ridges instead of the flat areas would change a reflective measurement. In Figure 3.1 it is visible that placement of the sensor over a ridge or flat area makes little difference in the UV reflections measured. The plot indicates the irradiance measured at each step increment in the EPP2000 for a ridge or flat area is essentially the same and should not unduly affect reflection measurements made. In the remaining preliminary measurements in Section 3.2.1, the zinc aluminium coated trapezoidal sheeting was used. The spectral measurements are unweighted. This is due to the process for calculating the spectral ratio which is calculated at every interval measured by the spectrometer. If total irradiance measurement and reflected irradiance measurements are weighted with an action spectrum over the same intervals, the process of taking a spectral ratio from these measurements would simply cancel out the applied action spectrum. Only when the ratio of the integrals of the UV spectra measured does the action spectrum play a more important role (as discussed later).

4.2.1.1 Distance

Previous studies on albedo measurement suggest that on the whole albedo is constant and therefore should be consistent over direction, distance and time of day. However, the inverse square law of light should alert us to the fact that intensity of radiation falling on a surface will be different at different distances, and in fact, the measured reflected irradiance will also decrease in intensity the further the sensor is from the reflective surface in question. How close or far away does a person need to be near a vertical surface in order to be affected by the reflections due to the vertical surface? In the case of a surface fully exposed to direct solar UV radiation, what is the limiting distance? As a part of the preliminary investigations, the reflected UV radiation was measured at different distances from a zinc aluminium trapezoidal vertical surface. Figure 3.2 shows the UV irradiance measured on a horizontal plane (also referred to as a global irradiance measurement) and the reflected UV irradiance measured at 10 cm steps from 10 cm to 50 cm distance from the vertical surface. As distance increases we can see a slight decrease in intensity over the UV spectrum, but no difference to the shape of the UV spectrum. Applying basic proportionality calculations to compare these spectral measurements, we find that intensity decreases by an average of 19% intensity across the spectrum from 10 cm to 50 cm, which does not appear to agree with the inverse square law. However, the feasibility of making measurements at 10 cm distance from a wall must give way to practicality. Would a person place themselves 10 cm from a wall? A person may lean against a wall (in which reflection may be irrelevant to all but a few areas on the body), but the likelihood a person may stand so close to a wall, for any extended period of time, may be considered unusual. It would seem more likely that a person in the vicinity of a wall is more likely to be working on something to do with the wall (such as construction workers or painters). In this case, the dependence of distance from a wall would depend on the activity being carried out. In most instances it would be reasonable to expect that distance from a wall may depend on the arm length of a person, as most activities would require using their arms to hold or manipulate a surface. However, as asked previously, what would the limit be from a wall influencing a person? Whilst this is not the most important question in this study, it is interesting nonetheless. Measurements taken further from the wall surface again at 1.0 m indicate that intensity once again drops the further out from the wall (Figure 3.3) and that when translated to a reflection measurement, the reflection ratio is significantly different (Figure 3.4). If the distance of 0.5 m is used, it can be considered a maximum practical standard, and it might make a suitable further study in using intensity proportionality to calculate influences of reflection intensity due to various distances from a surface.

4.2.1.2 Orientation

For horizontal surfaces, orientation is not an influencing factor. For vertical surfaces, the orientation of the surface is important due to influencing factors such as the position of the sun in the sky and seasonality and shading (however shading will not be addressed here). For instance, in the southern hemisphere the sun remains on the northern side of the sky, whereas in the northern hemisphere, the sun remains on the southern side of the sky. In Figure 3.5 and 3.6, the reflected UV irradiance from orientations facing the main compass points is measured at 0.5 m and 1.0 m respectively. At 0.5 m, we see there are two distinct reflected irradiances, where the north and west reflected UV irradiance are approximately the same, and the south and east measured reflected irradiances are approximately the same. These measurements were taken when the sun was midway in the sky (56° to 60° SZA), in winter. In Figure 3.6 however, there is a significant difference with the reflected UV irradiance measurement for the south facing wall at 1.0 m. Considering the UV irradiance would not be falling directly onto the south facing surface due to its orientation, this measurement is likely to be incorrect, taking into account the fact that the other three surfaces appear to have similar reflected UV irradiance to that measured at 0.5 m. If we look at the corresponding reflection ratio (compared to the global UV irradiance) in Figures 3.7 and 3.8 for 0.5 m and 1.0 m respectively, we can see the reflection ratio for the south facing surface measured at 1.0 m exceeds the ratio value of one for at least one third of the spectrum. It is important to note that we do not observe this large a reflection ratio in the measurements made at 0.5 m. Given the size of the piece of metal sheeting used to create the vertical surface (approximately 1 m^2 in area) it is extremely likely that at the distance measured from the surface, the sensor has detected direct UV irradiance from the sun as well as reflected UV irradiance, creating what appears to be an artificially high reflectance ratio. The use of reflected UV irradiance measurements at 1.0 m is unlikely to be useful if all south facing measurements at that SZA are going to be artificially inflated due to the small surface area (1 m^2) of this particular experimental design. This is an additional supporting reason for using the distance of 0.5 m for measurement of reflected UV irradiance. Overall, we can see that at one particular time in the day, the UV reflection from differently oriented vertical surfaces do differ as indicated in Figure 3.7. Interestingly, despite the low variation between the north and west reflected UV irradiance measurement in Figures 3.5 and 3.6 for both distances, Figures 3.7 and 3.8 display an average drop of 10% reflection from the north facing side from 0.5 m to 1.0 m, which is not observed for the west facing surface. One wonders if, during the 2° SZA variation between west and north measurements (approximately ten minutes separated their measurement time) that the north facing surface underwent more change in reflection due to directly facing the sun, than the western side (which is facing away from the sun at this time of day).

More importantly, if the difference between the horizontal and vertical surface orientation was compared, would a difference be found? In Figure 3.9 is the global UV irradiance, and the reflected UV irradiances from a horizontal surface and a north facing vertical surface. At the time of day indicated we see that the UV irradiance reflected is different between the horizontal and vertical surfaces, and when translated to a reflection ratio in Figure 3.10, it is obvious there is significant difference between reflected UV irradiance from a vertical surface and a horizontal surface. Previous studies considered in the literature review has concentrated on reflection from horizontal surfaces, indicating that reflection from a vertical surface has not been as well understood in the past, and this present research therefore provides important findings on the UV reflection from vertical and inclined surfaces.

4.2.1.3 Time of day and position of sun in sky

As we saw from the previous section's discussion, the time of day and the position of the sun in the sky are important to reflection occurring from differently orientated surfaces and more so when considering the difference between UV irradiance reflected between horizontal and vertical surfaces. In the previous section, the example only supplied a measurement at one SZA. In Figures 3.11 (north facing vertical surface) and 3.12 (horizontal surface) there are four reflection measurements presented for differing SZA and SAA. Figure 3.11 shows significant differences in spectral UV reflection over changing SZA and SAA, most particularly the largest SZA measurement, which is 20° larger than the mid-morning SZA measurement. In Figure 3.12, it is apparent that the 20° SZA variation does not affect reflection from the horizontal surface as much as the vertical surface in Figure 3.11. The shape of the reflection spectrum at this SZA and SAA is also significantly different to the rest of the reflection measurements (both vertical and horizontal). The data shown in these figures indicate it is important to take into account SZA and SAA when measuring UV reflection, especially from non-horizontal surfaces.

4.2.2 Surface type

Surface type affects the reflection occurring from a surface. This investigation involves man made surface types rather than natural surface types. Like the preliminary measurements, the first UV reflection measurements were made on zinc aluminium coated trapezoidal sheeting. This surface type is shiny and smooth. Figures 3.13 to 3.20 display the original data obtained on this surface type. In Figure

3.13, there is a variety of UV reflection measurements made at various SZA and SAA from a north facing surface, which again shows that UV reflection at large SZA are significantly different to those measured at smaller SZA (55° and below), where the shape of the spectral UV reflection produces minimum UV reflection at 320 nm and increasing at different rates per wavelength on both sides of this wavelength. Figure 3.14 shows reflection from a horizontal surface over varying SZA and SAA, but it is more consistent across the spectrum, and only deviates at the shorter wavelengths. Figure 3.15 takes the information from Figure 3.14 and expresses it as the spectral average and spectral maximum and minimum, indicating that the reflection from a horizontal surface ranges throughout a winter day from 0.22 to 0.32 (at 320 nm or higher). The average is just below 0.3. Compared to measurements made by (Heisler & Grant 2000) where sand is measured at 0.18, which is a rough surface, the reflection measured from this surface seems reasonable. Also, in comparison to many of the previously established reflective capacities, it is significantly higher, which may contribute to significant influence in UV exposure. Figure 3.16 shows various reflection measurements from an inclined surface. The inclination of this surface is at 35° from the horizontal, which is the angle of an average roof incline. Of the measurements made, these spectral reflections appear much higher than either the spectral reflections from horizontal or vertical surface. Averages are taken from the horizontal, vertical and inclined surfaces, and in Figure 3.17 the data can be compared. Here we see some evidence that at lower SZA inclined surfaces have higher reflection than vertical surfaces which in turn have higher reflection than horizontal surfaces. At larger SZA, the shape of the reflection from inclined and vertical surfaces are slightly different, with the vertical surface having both higher maxima and lower minima than the inclined surface. Figures 3.18

to 3.20 indicate vertical and inclined measurements on east, south and west facing surfaces respectively. From the south and east facing surfaces, some data has not been included, specifically when it was difficult to tell if direct irradiance had influenced reflection readings from these surfaces at the smaller SZA (and sometimes larger SZA in the case of the east facing surface). In most of the cases, reflection at some point in the spectrum exceeded unity, therefore was identified as being artificially influenced by direct irradiance falling on the sensor and removed from the presented data. In the case of the west facing surface in Figure 3.20 reflection is rather high at values of 0.6 and above. This data has been retained as the data was collected when the sun was behind the sensor, which means direct irradiance will not have affected the sensor.

With such a lot of data that clearly emphasizes the factors identified in the preliminary measurements as variables in the reflection measurement from type of surface, there needs to be a consistent and concise method that can allow comparisons to other types of surface reflection yet not require the entire spectrum to express the data. With the above discussed data, it was observed that in the spectrum, the wavelength of 320 nm either represents a minimum reflection value (at larger SZA) or a maximum reflection value (at smaller SZA). In some cases, the spectral reflection is consistent across the spectrum. Therefore, for comparative purposes, the reflection at 320 nm was taken as a representative reflection value for measurements made per surface. Appendix 7.1 presents the remaining graphed data for the ten surface types explored in Winter 2007, with the reflection at 320 nm tabulated for all types in Tables 3.1 and 3.2, including zinc aluminium trapezoidal, zinc aluminium corrugated, beige trapezoidal, cream trapezoidal, cream corrugated, medium blue trapezoidal, insultec coated trapezoidal, black trapezoidal, dark red trapezoidal and pale green trapezoidal.

The top line of reflection data in the tables represent the average horizontal reflection throughout the day of measurement at 320 nm and is fairly indicative of the comparative reflection capabilities of the surfaces presented. Zinc aluminium trapezoidal and zinc aluminium corrugated appear to have the same reflective capacity from a horizontal surface, and the same is observed for the cream trapezoidal and cream corrugated surfaces (Table 3.1), which emphasizes that the difference between reflection due to surface shape at this scale is not significant on a horizontal surface. However, when we consider the reflection from a north vertical surface (north receiving the most direct reflection over the day), we see differences in reflection at early morning large SZA between the two surface types and more so in the zinc aluminium coated surface. As the day progresses, this difference decreases, and compared to the east, west and south vertical surfaces, has the most observed difference in reflection (including inclined surfaces). In fact, for south and east vertical surfaces these reflection values are almost the same. However, the positioning of the sensor for the measurements from vertical surfaces should be questioned. Early in the morning the east facing vertical surface should have the sun positioned behind the sensor, which should mean the irradiance recorded by the sensor facing the surface will be reflected or diffuse irradiance. The south facing surface will have the position of the sun at an angle to the sensor, and with the sensor reportedly able to record irradiance at 180° around the sensor, it is highly probable that direct irradiance may be influencing the reflection measured from the south facing surface.

The orientations and times that may have resulted in artificially inflated reflection due to SZA and SAA have been identified as: west vertical early morning, west inclined early morning, east vertical afternoon and east inclined afternoon. Surface positions and times that may influence reflection measurements in an unknown way due to irradiance from above the sensor include east vertical midday and south vertical midday.

For the paint coated surfaces it is interesting to note that the black and dark red horizontal surfaces have half the reflection than that of the cream and insultec coated surface (insultec is a white/gray paint coating used as a thermal insulator). One would expect colour not to influence reflection within the UV spectrum.

From this data some preliminary general conclusions can be made. Inclined zinc aluminium coated surfaces will have higher reflection than its vertical counterpart oriented in the same direction, except for south facing surfaces where it is possible SZA and SAA have influenced the data in some way to show the opposite. Inclined surfaces also have higher spectral reflection than horizontal surfaces. For paint coated surfaces the opposite occurs, where reflection is higher for vertical surfaces than compared to inclined surface reflection.

4.2.3 Repeated spectral reflection measurements

In the latter months of 2007, the fibre optic attached to the EPP2000 was damaged preventing further repeated measurements over the spring and summer. Before the damage occurred, the incident irradiance at different times of day was explored as shown in Section 3.2.2 and summarized in a broadband analysis in Tables 3.1 and 3.2. All reflection measurements were made relative to global irradiance, (down-welling) irradiance. For a vertical or inclined surface, the changing position of the sun due to SZA and SAA will affect the total down-welling irradiance the surface is exposed to, particularly when measured at significantly large SZA. Even for horizontal surfaces at large SZA, a global irradiance measurement made on a horizontal plane will not account for all of the solar irradiance, due to the surface area of the sensor. For example, a reflection measurement from a vertical surface orients the sensor perpendicular to the horizontal position of a global irradiance measurement as shown in Figure 4.1.

At a large SZA, the position of the sun will approach a similar orientation to the perpendicular oriented sensor (providing the azimuth positions the sun facing the vertical surface in question). As a result of position of the sun, the amount of irradiance reaching the sensor will be less than if the sensor was oriented towards the sun. Figure 4.2 displays an approximated response area of the sensor according to approximate position of the sun in the sky.

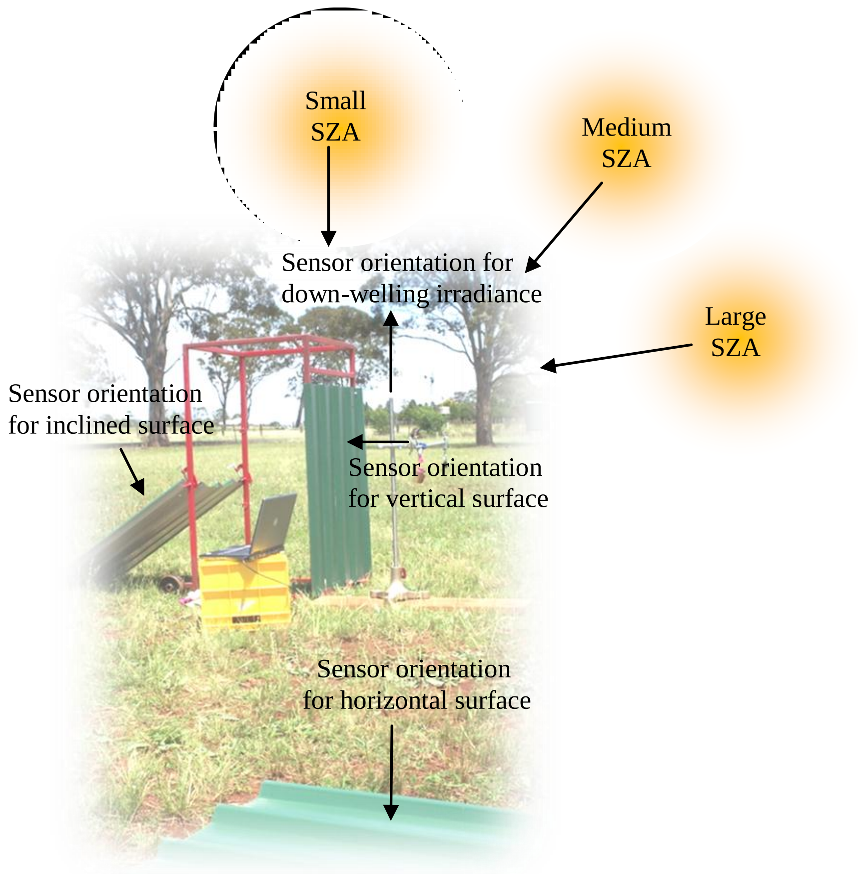

Figure 4.1 – Orientations of the sensor for global irradiance measurements and reflected spectral measurements from different surface inclinations, relative to the position of the sun.

In Figure 4.2, it is obvious that the larger the SZA compared to the horizontal plane at which the down-welling irradiance is measured from, the less irradiance will be able to reach the sensor. This means that the reflection from a horizontal surface at larger SZA will overestimate the proportion of reflected irradiance from a horizontal surface when it is measured relative to the down welling irradiance, with only a small area of the sensor exposed to the incoming irradiance.

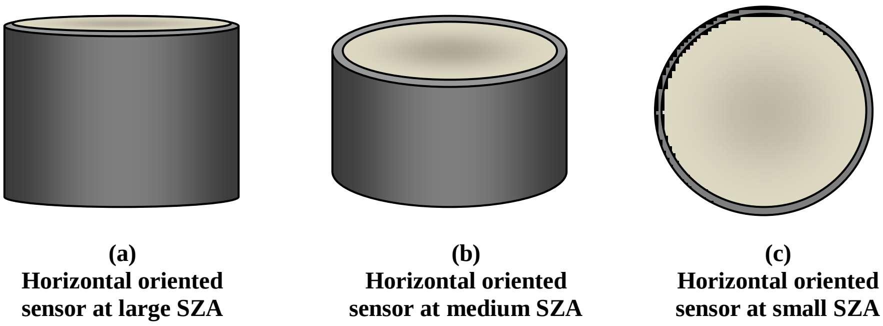

Figure 4.2 – Approximate surface areas exposed to UV irradiance from global (down welling) irradiance measurements relative to different SZA.

When measuring reflected irradiance from a vertical surface with the sun at a large SZA (ideally located behind the sensor), then the amount of area the sensor is exposed to from the reflected irradiance would be the same as example (c) in Figure 4.2 but the global irradiance measurement will be the same as example (a) in Figure 4.2. Both would underestimate the down welling irradiance, artificially inflating the proportion of reflected irradiances. The overestimation and underestimation of reflection from differently oriented surfaces can explain why in some measurements, reflective ratios were exceeding unity, which of course would mean that more radiation was being reflected than was incident on the surface. It is known that shiny metals are poor emitters of radiation which means the excessive reflection values cannot be accounted for in this manner, therefore the technique of reflection measurements required refining and adjusting.

4.2.3.1 Refining the reflection measurement technique

Albedo is measured using the ratio of up-welling irradiance measured from a surface to the down-welling irradiance incident on a surface. For a horizontal surface, albedo is a mostly reasonable method of reflection measurement. However, as pointed out in the previous section, this traditional method of measuring reflection is inadequate for measuring reflection from non-horizontal surfaces (and sometimes horizontal surfaces) due to changing SZA and SAA of the sun, and the orientation and position of the non-horizontal surface in question. Reflection is therefore a more appropriate term to use however, it is important to define what reflected irradiance is being measured relative to, particularly when reflection from differently oriented surfaces is going to be compared.

As the sensor is held perpendicular to each surface in order to measure total irradiance reflected from a surface, it would be reasonable to assume that the incident irradiance measurement should be made at a 180° orientation to the reflected irradiance orientation sensor position. This however, would be limiting again for non-horizontal surfaces, as the SZA and SAA would still affect the total area of the sensor being able to detect irradiance. This also does not allow a common reference point for all types of surface orientations if the reflection from different surface inclinations needs to be compared.

The only common reference point is the sun itself. Only some surface orientations would have limited solar irradiance incident on the surface and that would be due to the surface not directly facing the sun. There are two forms of UV radiation that will be incident on a surface, and these are direct and diffuse radiation (as defined in the Literature Review). In the cases of surfaces that are oriented towards the sun, provided factors such as clouds or structures do not cover the sun, there will be both direct and diffuse irradiance incident on the surface. The time of day (and therefore SZA and SAA) will affect the direct irradiance incident on a surface but diffuse irradiance does not have the same dependence on time of day as direct irradiance does. That means the total irradiance on a surface changes as differing amounts of direct and diffuse UV irradiance combine to make a changing total UV irradiance on a surface throughout the day. Therefore, it is logical to use the sun as the point of commonality between different surface types in order to compare reflectivity to account for the changing total UV irradiance on a surface. As a result, the measurements made from this point forward have measured reflection with respect to the total UV irradiance measured from the direction of the position of the sun in the sky. This measurement will be referred to as total irradiance (both direct and diffuse irradiance). Repeated reflection measurements will then be the ratio of the reflected irradiance to the total irradiance measured from orienting the sensor towards the position of the sun in the sky.

The difference between these two methods of reflection measurement is apparent in Figures 3.21 and 3.22. The effect of the incorrect measurement was first clearly displayed in Figures' 3.11, 3.13, 3.16 and 3.17 – where the larger SZA measurements show anomalous reflection measurements compared to the rest of the data indicated. Figure 3.21 shows reflection measurements made throughout a day in Autumn 2008 using the initial reflection measurement technique. Here reflection exceeds unity at shorter wavelengths, and there is increasing reflection per wavelength from 320 nm onwards with a large range of reflection ratios in the upper UVA spectrum. In Figure 3.22 the reflection measurements using the refined technique no longer show reflection exceeding unity, and significantly less spread of the reflection measurements across the UV spectrum. A shift in the proportion of reflection is also observed, where the least reflection measured has decreased by a minimum of 0.05 at 400 nm and similar at 320 nm. The change in reflection due to SZA and SAA is still present but with a much lower degree of variation.

4.2.3.2 Observations in repeated spectral reflection measurements

4.2.3.2.1 Zinc aluminium trapezoidal

In the repeated spectral reflection measurements for zinc aluminium trapezoidal, it is apparent there are significant differences between the preliminary spectral reflection measurements (Section 3.2.2.1) and the repeated experiments (Section 3.2.3.1). At larger SZA, the spectral reflection no longer exceeds unity in the UVA waveband and in fact reflection decreases with increasing wavelength (Figure 3.23). At larger SZA the reflection in the UVB waveband is higher than at lower SZA and the wavelength of 320 nm is no longer a maximum or minimum reflection value within the UV spectrum. At medium SZA (approximately 45°) the reflection is approximately equivalent across the spectrum. For horizontal surfaces (Figure 3.24), the spectral reflection approximates the shape of the vertical reflection, but with less intensity at larger SZA. The largest range in spectral reflection is observed from the inclined plane (Figure 3.25) over all SZA.

Comparing the three surface orientations for the larger (8 am to 9 am) SZA in winter (Figure 3.26 section (a)), the inclined surface has a slightly higher average reflectivity than the vertical surface, and in turn the vertical surface has a slightly higher average reflectivity than the horizontal surface. At medium SZA (9 am to 1 pm) range, the vertical and horizontal surface reflection have little variation between the averages, whilst the inclined surface has almost twice the reflective capacity than either the horizontal or vertical surface.

The measurements made in winter 2010 were repeated in spring 2010 (Figure 3.26 (b)), and the averages were computed for both. It is apparent that winter shows some larger average spectral reflections than spring, and it can be argued that this is a result of the SZA range for each day of measurement. In winter, the range may only encompass 70° to 40° SZA, whilst the SZA range in spring is much larger, with the smaller SZA reaching 10°. It is possible that more measurements made at even lower SZA will result in lower reflection measured, and hence lower the average spectral reflectance. However, looking at the data presented in Figures 3.27 and 3.28 for vertical surface reflection, there may be a limit to the lowering reflective capability. The data from winter and spring 2010 is averaged and the minimum and maximum spectral reflections calculated per wavelength (Figure 3.27). The minimum reflection remains above or at 0.1 for most of the spectrum. In Figure 3.28, all spectral reflection measurements taken over the course of this research have been averaged and plotted per wavelength, and there actually appears to be little variation within the averages of particular months. This may be an indicator that there might be a minimum and even a maximum reflection occurring from a vertical surface which results in similar averages.

As a result of there being the lack of a specific wavelength at which there is an identifiable characteristic in reflection, a different method of presenting average reflection per spectral measurement was chosen. According to the albedo measurements made in a number of the studies explored in the literature review, it was common practice to use an RB meter, or erythemally weighted irradiance meter. It was deemed practical to calculate the erythemal broadband reflection since most studies are concerned with erythemal exposures to humans. Each spectral scan made in determining reflection was weighted with the erythemal action spectrum. The total weighted irradiance over each scan was integrated from 280 nm to 400 nm. To calculate the erythemal reflection, the ratio of the integrated weighted irradiance reflected to the integrated weighted direct irradiance measurement is determined. The resulting ratio was then plotted against SZA to determine if there is a relationship between SZA and reflection from this surface (Figure 3.29). It is clearly visible that there is a distinct relationship between SZA and erythemally weighted reflection, and it can be most effectively represented by a quadratic polynomial model. Grouping the data in various SZA ranges, shows that the trend between SZA and erythemally weighted reflection is interdependent (Figure 3.30). In addition, it is possible to compare the vertical, horizontal and inclined reflection per SZA grouping (Figure 3.31) however it should be noted that in this data set, there were significantly more measurements made from a vertical surface in zinc aluminium trapezoidal than there was from horizontal or inclined reflection, despite using all the data collected from 2008 to 2010. Finally, comparing weighted reflection measurements against the direction the surface is oriented or position is possible in Figure 3.32, where it is apparent that even though the different groups do not follow as clear a trend as the vertical surface does, together all the reflection data collected from a zinc aluminium trapezoidal surface follows a SZA dependent relationship.

4.2.3.2.2 All other metal surface types

Zinc aluminium corrugated shows similar spectral reflection to zinc aluminium trapezoidal, as shown in Figures 3.33 to 3.36. There were not as many erythemal reflection ratio data values obtained, therefore Figure 3.33 shows a less obvious SZA dependence and a weaker trend due to SZA. There were more erythemal reflection ratios available for cream trapezoidal (Figure 3.37) however the data is widely spread, and only shows a weak trend with SZA. Surprisingly, the maximum spectral reflection in Figure 3.38 is very high in the UVB waveband, which is not that much lower than the maxima observed for zinc aluminium coated surfaces. The average spectral reflection per measurement session in Figure 3.39 for cream trapezoidal does show a gradual decline in spectral reflection intensity as the measurements gradually progress from cold months to less cold months, and this change between seasons is markedly shown in Figure 3.40 with less than 0.1 reflection for most of the UV spectrum in spring.

There were less measurements carried out for cream corrugated so there was not enough data for erythemal reflection ratios, and most of the presented data in Figures 3.41 to 3.43 show very similar results to cream trapezoidal. There were more significant data measurements made for pale green trapezoidal, and the erythemal reflection ratios in Figure 3.44 appear to show some trend, although there are very few measurements recorded at smaller SZA, so it is difficult to tell if this surface type follows a similar trend to zinc aluminium coated surfaces according to SZA. Placing this data into groups of SZA, the trend is not as strong as zinc aluminium coated surfaces and drops off at larger SZA with a larger standard deviation (Figure 3.45). Interestingly, the vertical reflection measurements appear to exceed those made by horizontal or inclined surfaces, and the reasoning for this is discussed later in the UV exposure measurement section. Again, like the cream coated surfaces, pale green trapezoidal appears to have a very high maximum spectral reflection (Figure 3.47). Like the cream coated surfaces, the average spectral reflection for each set of measurements indicates that the months with larger SZA range have lower spectral reflections. Some of these measurements were made in April, which almost match the months of lower SZA ranges investigated in May and later. It would be interesting to know when the changes between seasons really start to show, although much more data would be required to answer this question. Looking at the breakdown of data in Figure 3.49, like the cream coated surfaces there are changes between season, but not so much difference between the vertical, horizontal and inclined reflections, which is very different to the breakdowns observed for zinc aluminium trapezoidal (Figure 3.26) and zinc aluminium corrugated (Figure 3.36).

The data for the remaining surface types are shown in Appendix 7.2, since there was a lot of data collected, but the average spectral reflection for each surface type is summarized in Figure 3.50 for all measurements made (large and small SZA) and for just the measurements made at lower SZA (Figure 3.51). It is becoming apparent from these charts that the coating of the metal surfaces is very important to the spectral reflection observed from each surface type. The zinc aluminium coated surfaces are clearly delineated from the paint coated and thermal coated surfaces, at nearly half the spectral reflection observed for the paint coated surfaces compared to the zinc aluminium surfaces. Using this information, analysis of erythemal reflection ratios of all the paint coated surfaces as a total group may determine if there is a trend due to SZA for the surface group. This analysis has been produced from the charts already displayed and has been combined into Figure 4.3.

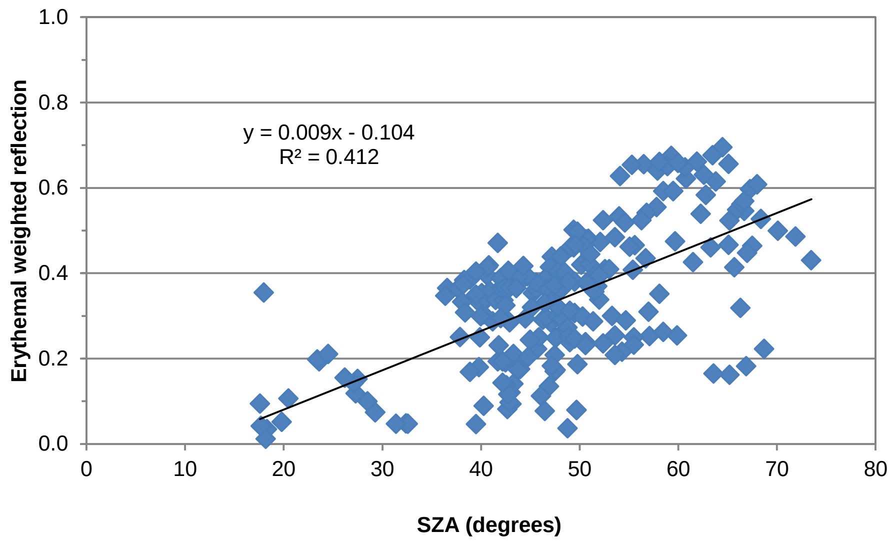

Figure 4.3 – Erythemal reflection ratios for all paint coated surfaces for a vertical north facing surface.

The trend is about the same compared to that seen for pale green trapezoidal, with a few more measurements made at lower SZA, however the spread is still very broad around the line of best fit through the data. Further data at lower SZA would need to be obtained to be sure that a linear trend is the most appropriate as a polynomial trend at this stage does not significantly change the associated R^2. However, it is possible at this stage to suggest that for paint coated surfaces, the reflection from vertical surfaces is dependent on SZA.

4.2.3.2.3 Non vertical surfaces in situ

On a rooftop at the University of Southern Queensland there are a number of surface types at various orientations, of which reflection measurements were taken over the course of a day. The three surfaces investigated were galvanized steel, grey paint coated trapezoidal (the roof surface) and transparent plastic (the cover of a sky light). Galvanized steel is steel coated in zinc, and this particular surface was inclined at 5.1° from the horizontal, facing towards the east. Figure 3.52 indicates that the reflection measured from this surface is comparable to zinc aluminium coated steel surfaces. The grey coated trapezoidal roofing was horizontal, with reflection fairly low across the UVA spectrum, consistent with the measurements made on other paint coated surface types in Figure 3.53. The transparent plastic was essentially a large square based transparent plastic pyramid. Of the four faces, the west and the north were exposed to direct UV irradiance for most of the day. The planes of the pyramid were inclined at approximately 45° to the horizontal, but for interest, two different sensor orientations were used, with an orientation of the sensor as if it were facing a vertical plane, and orientated perpendicular to the plane (inclined sensor position). Figure 3.54 displays both sensor orientations over averaged spectral reflection measurements. When the sensor is oriented as if taking vertical reflection measurements, it shows a higher spectral reflection in the shorter UV wavelengths than the other sensor position. However, it is unknown at this stage if this is due to more reflected UV irradiance, or other confounding factors such as greater exposure to diffuse or direct UV irradiance rather than when the surface is oriented perpendicular to the inclined plane. There will be a further discussion on this topic later in this chapter. This figure also indicates that reflection from the plastic surface is SZA dependent.

4.2.3.2.4 Vertical surfaces *in situ*

The structure and composition of a building is important to the reflective capability of a surface. Shading on the structure will influence if a surface is highly reflective or not. On the University of Southern Queensland's Toowoomba campus, there is a building with dark tinted glass. Most of the time, shading from the building prevents direct UV irradiance striking the glass, except in the afternoons when the sun is in the west. It is usual for the tinted windows to be exposed to total UV irradiance for at least an hour or so at this time of day. Sometimes it is less than an hour, when the sun passes behind the trees located on the opposite side of the road. This area of the building is also a bus stop. Despite the dark tinting, the glass is still transparent, and will absorb most UVB radiation. Previous research (Heisler & Grant 2000) has suggested that UV irradiance (specifically at 300 nm) striking glass at large incident angles is more likely to be 100% reflected, whilst angles of 70° incidence or less result in just 10% reflection. Therefore it was initially unknown if this surface type would produce much reflection with small incident angles. Figure 3.55 displays the spectral reflection recorded for a number of distances from the glass which appears to be consistent in intensity for small distance changes, however, when using just one distance over a short period of time, there is considerable variation in the spectral reflection of the darkly tinted glass (Figure 3.56). At this stage it is difficult to determine if these reflection measurements are influenced by any other factor, however, this should definitely be further investigated, particularly as this area is a gathering place for members of the public. Heisler & Grant's (2000) work indicates that glass is going to be more of an issue when shading is not present. An example of this could be irradiance at a small SZA (and therefore at large incident angle) striking a vertical glass façade on a building, may be just enough to affect the UV exposure of a person standing at the base of the building. Since this is not occurring for the measurements made in this study, it is not likely that the maximum influence on UV exposure is being observed.

In Figure 3.57, the average spectral reflection from a white painted fibro building is presented, and here it is visible that within the UVA spectrum there is relatively low reflection as compared to metallic surfaces. However, like the metallic surfaces already explored, the reflection within the UVB range reaches relatively higher reflection values even at larger SZA. This seems unusual, particularly when painted coated metallic surfaces have been shown to have lower reflective capabilities within the UVB spectrum at lower SZA angles, and because the base of the surface is metal and not fibro, one might expect UV reflection to be higher for metal. Later discussion will explore exposures measured using dosimetry which indicated that the influence of the erythemally reflective capacity of the wall was in fact very low (Section 3.3.7.1, Figure 3.77). There are some possible influencing factors that could be affecting the reflection measurement. In late Autumn, the proportion of UVB to UVA in the spectrum is relatively low even at a medium value SZA. UVB radiation is more highly scattered in the atmosphere than UVA (as given by the Rayleigh relationship between atmospheric particle size and wavelength). Despite low amounts of UVB radiation present, the effect of scattering will increase the relative amount of diffuse UVB radiation. It is possible that diffuse UVB not reflected from the surface may be overly influencing the reflection measured. However, the issue with this postulation is that when a total UV irradiance measurement is made, this measurement should account for all direct and diffuse UV irradiance present. Therefore, a reflection calculation would take into account the diffuse UVB measurement, since the diffuse component should be present in both the total and the reflected UV irradiance measurements. A similar spectral reflectivity shape is recorded from a red brick wall (Figure 3.58) and the same aforementioned issues should also be considered with the spectral reflection measurements observed.

4.3 Quantification of biological effect of UV exposure due to vertical UV reflective surfaces

The justification for choosing just a few types of metal sheeting to use in determining how a reflective wall may affect an individual's exposure was established in the methodology and results section. The common use of the surface type indicates that it potentially could be a hazard compared to a rarely used surface type.

Polysulphone dosimetry is an effective method of approximating erythemal UV exposure due to its spectral response similarity to the erythemal action spectrum, and since the size of a dosimeter is small, it can be attached at various orientations and positions. The use of manikins negates the need to have humans exposed to excessive levels of UV exposure. It can be argued that a person would be unlikely to spend an entire day standing facing a wall for several hours at a time, and that shorter time intervals would be more probable, however it can be difficult to predict behavior patterns of people, therefore it is logical to investigate all possible situations of potential UV exposure at maximum expected exposures. By breaking the erythemal exposure measurement down into smaller intervals of time, we can observe possible changes in erythemal exposure over time. Therefore if we wanted to apply the observed information to a real life situation, it would simply be a matter of considering the time interval and time of day to approximate the influence to erythemal exposure experienced by a person such as a construction worker.

In these experiments, the data were collected in hourly intervals. The choice of this time interval was more about having enough time to remove the head forms to a UV free environment, replace the exposed dosimeters with unexposed dosimeters (a total of forty-five dosimeters to be replaced) and replace the head forms outside to repeat the experiment. Using this time interval, up to four hours of total erythemal exposure could be measured in one day. As a result it required two days to build a profile of seven or eight hourly intervals over a total day of potential erythemal exposure. In most cases the weather conditions were fairly comparable when the measurement days were consecutive, and during the experiments, the weather was observed and recorded. Forecasts were used to try and determine sequential days of similar weather conditions, however some experiments had several days between the two days of measurement, due to poor or unstable weather conditions. The ideal weather for erythemal exposure measurements were on a clear day with low to no cloud, although cloud cover up to about 50% (or four oktas) still would allow reasonable measurement of influences of reflective structures, providing the sun was not obscured for long periods of time due to slow moving cloud. In seeking to use clear weather, it is assumed that the data obtained would represent a maximum of influence, providing the surface is oriented towards the sun for most of the day. This was done by orienting the surfaces towards the north.

Dosimeters were placed in set positions on the head form in order to be able to analyse the resulting erythemal exposure measurements obtained from each dosimeter position as well if desired. The body position has been shown to affect the erythemal exposure received (Hoeppe et al. 2004; Downs & Parisi 2009), even so the head form would be expected to experience an average exposure if a person was moving around. Therefore, to approximate the head form's overall erythemal exposure, the erythemal exposure experienced by each dosimeter was averaged across all of the head forms' dosimeters. As detailed in the Methodology, two controls were used to compare to the reflective wall's influence. A non-reflective wall was used to account for the presence of a structure even if it isn't capable of producing reflection, and a third head form placed where no structure can influence the exposure.

Originally the scope of this study sought to include vitamin D_3 weighted UV exposures as well as erythemal UV exposures. Some of the initial work in measuring UV exposures carried out both calculations, however it was soon noticed that despite the differently weighted action spectra the UV exposures for each biological effect producing given exposures (vitamin D_3 is measured in J/m^2 not SED); the resulting ratios produced by the differently weighted data were almost exactly the same. It was decided that erythemal UV exposures would be more relevant to this study. If required, there are various methods in which to convert erythemal exposure to vitamin D_3 exposure (for example Pope et al., (2008)).

4.3.1 Influence of reflective walls

4.3.1.1 Zinc aluminium trapezoidal Autumn 2008

The first reflective wall to be explored for reflective UV influence was zinc aluminium trapezoidal. Figure 3.59 expresses the average erythemal exposure per head form as detailed by the earlier discussion for each form in its specific location (near a non-reflective wall, a reflective wall or no wall), and is also tiered into three groups. In section (a) of the figure, all the dosimeters located on the head form were used to calculate the total average erythemal exposure, and for most of the day, for each hourly interval, it appears the erythemal exposure received by the head form located near the reflective wall exceeds the erythemal exposure received by the head form near the non-reflective wall and the head form near no wall. The clearly delineated difference between the reflective wall head form and the other two head forms from the morning to midday intervals, are not as defined in the afternoon, and the erythemal exposures received by the head form without a wall approaches the erythemal exposure received by the head form near the reflective wall.

Whilst section (a) shows that the presence of the reflective wall seems to be influencing the total erythemal exposure of a head form, some of the dosimeters on the head form are located in positions that may not be directly influenced by the presence of the reflecting wall, such as the back of the head, and back of the neck. The dosimeter located at the top of the head, and the dosimeters located on both shoulders also may or may not be influenced by the presence of the reflective wall. In order to see if these particular dosimeter positions have an influence on the total average erythemal exposure, the erythemal exposures measured from these dosimeters were deducted from the average calculation and a new head form average erythemal exposure was calculated using the remaining dosimeters, as shown in section (b) of Figure 3.59. This group is therefore labeled ‘face, chest and ears’ indicating which dosimeters have been included in this particular group average. In this section a distinct drop in average erythemal exposure per hourly interval is visible, since most of the remaining dosimeters are unlikely to have received as much direct UV irradiance as the dosimeters deducted from the average. However, the difference between the average erythemal exposures for the different head form locations has increased slightly, except for the erythemal exposure received from 1 pm to 2 pm in which the erythemal exposure received by the head form with no wall nearby matches the erythemal exposure received by the head form near the reflective wall. At this stage it is uncertain if this matching erythemal exposure is due to the SAA, or some other unknown factor. The consideration of this quirk being due to the SAA might then be negated due to the hour following in which the erythemal exposure received by the head form near the reflective wall again exceeds that erythemal exposure received by the head form with no wall.

In section (c) of Figure 3.59, the dosimeters located on the face were investigated. There are only five dosimeters located on the face, including forehead, nose, chin and both cheeks. Looking at the average erythemal exposure experienced from 10 am to 1 pm, compared to the average erythemal exposure received in section (b), there is an increase in the average erythemal exposure of about 0.1 to 0.2 SED experienced by the head form located near the reflective wall, whilst an increase in exposure is also observed for the head form located near no wall. However, the increase does not match for both head forms, and there appears to be an increase between the proportions of the two exposure measurements. Referring to Table 3.3 which expresses the proportion between the head forms, by comparing each head form's relative exposure, using the same time frame with facial features averaged erythemal exposure compared to face, chest and ears averaged; the period of 11 am to 12 pm experiences an absolute increase of 0.13. The sun reaches the maximum SZA during this time period (before midday in clock time). It is possible that the maximum SZA allows more direct irradiance to strike the dosimeters on the face causing the measured increase, however, it does not explain the increased relative difference between the head forms average erythemal exposure, so it may be concluded at this point, that the zinc aluminium trapezoidal wall is increasing the erythemal exposure received by the head form by reflecting UV irradiance onto the head form and particularly in the facial region. This can be confirmed by considering the head form located near the non-reflective wall, and it clearly receives less average erythemal exposure compared to the head form located near the reflected wall and the head form located near no wall. Table 3.3 shows that comparing the average erythemal exposure of the head form near the non-reflective wall it experiences an average of 85%, 55% and 49% respectively of the averaged exposure for the entire head form, face chest and ears, and the face only, near no wall, indicating that the wall is effectively blocking erythemal exposure to the head form (compared to the head form near no wall). In the same token, the average erythemal exposure received by the head form near the reflective wall is 144%, 274% and 312% higher than the average erythemal exposure for the entire head form, face chest and ears, and the face for the head form located near a non-reflective wall. Therefore, the zinc aluminium trapezoidal wall is increasing erythemal exposure significantly compared to a non-UV reflecting surface. Finally, comparing the erythemal exposure obtained from the head form near the reflective wall to the head form near no wall, increases of 22%, 44% and 50% are observed for the entire head form, face chest and shoulders, and face only respectively. Therefore, the zinc aluminium trapezoidal wall is increasing erythemal exposure on the head form significantly compared to when a head form is not located near any surface.

4.3.1.2 Pale green trapezoidal Autumn 2008

This surface is a common colour and type used in many residential settings, including use for buildings such as sheds, roofing and fences. Figure 3.60 at first glance indicates that in section (a) the erythemal exposures experienced by the head form located near the pale green trapezoidal reflective wall approach the erythemal exposures experienced by the head form located near a zinc aluminium trapezoidal wall, at least for the hour preceding midday. This hour interval indicates significant difference between the erythemal exposure experienced by the reflective, non reflective and no wall head forms. However, an exception is also observed at this time, where the erythemal exposure received by the head form located near the non-reflective wall actually exceeds the erythemal exposure received by the head form near no wall. However, the remaining hourly intervals for this surface type and those of zinc aluminium trapezoidal do not display this observation with no other similar measurement. Looking at section (b) of Figure 3.60, it is apparent that the average erythemal exposure for the face, chest and ears is significantly different to the average erythemal exposure for all dosimeters. Here the erythemal exposure received by the head form near the non-reflective wall is less than the erythemal exposure received by the head form near no wall, and in fact the erythemal exposure of the head form near the reflective wall is also less than the head form near no wall. This same trend is observed throughout the hourly intervals in section (b) and also in section (c), with the averages observed between section (b) and (c) remaining very similar. Table 3.3 indicates that in all cases except for the hour interval before midday for all dosimeters, the average erythemal exposure of the head form near the pale green trapezoidal surface is less than that received by the head form near no wall. Despite the fact that previous data shows that reflection from the pale green trapezoidal surface is present and can be fairly high at large SZA, it appears that this reflection does not appear to significantly influence the erythemal exposure received by a head form and does not increase erythemal exposure above the erythemal exposure received by a head form near no wall. It does however appear to marginally increase the erythemal exposure compared to a head form near a non-reflective wall in some cases. Overall, this would indicate that some reflection is definitely occurring from the pale green trapezoidal surface however it is less than the diffuse UV from the sky view that is blocked when a wall is there. At large SZA, it is likely that despite the large reflection ratios for the UVB waveband, due to the low quantities of UV irradiance at that time of day, the total effect on UV exposure is low also.

4.3.1.3 Cream trapezoidal Autumn 2008

The erythemal exposure measured due to the influence of cream trapezoidal sheeting was only carried out for half a day of measurements due to unstable weather conditions before and after the day of measurement. Despite that, the data remaining for the half day of measurement gives a fairly reasonable spread of data as it was measured every alternate hour, and comparing Figure 3.61 to Figure 3.60 (pale green trapezoidal) shows a similar pattern for the same hour intervals of measurement. Section (a) of Figure 3.61 shows much lower average erythemal exposures than that in Figure 3.60, however sections (b) and (c) actually show a very similar average erythemal exposure compared to Figure 3.60. This confirms that the colour of paint coated trapezoidal surfaces does not appear to influence UV radiation significantly, at least for white based colours (where a colour is built on a base of white, unlike darker colours which are built on a base of black or similar dark shades). As the influence of similar coloured surfaces on erythemal reflection appears to be minimal compared to measurements made away from a vertical surface, it would not be necessary to carry out erythemal exposure measurements on dark based paint coated surfaces as the expected influence is going to be comparable to the erythemal exposures received near a non-reflective wall or higher, but not comparable and most likely significantly lower than the erythemal exposure received by a head form near no wall.

4.3.1.4 Dosimeter position comparison Autumn 2008

Figure 3.62 indicates the variation in erythemal exposure due to dosimeter position on a head form averaged over all hourly interval measurements using the ratio of the erythemal exposure received from a head form near the reflective wall to the erythemal exposure received from a head form near no wall. It is likely that the slight differences observed between the pale green trapezoidal surface and the cream trapezoidal surface is due to the lower quantity of data collected from the cream trapezoidal surface. Both these surfaces indicate lower erythemal exposures than compared to the head form near no wall, except for the top of the head and the back of the head, which are both dosimeters that would be unlikely to be significantly influenced by the wall. As the top and the back of the head should receive the same exposure on each head form, the variation observed in Figure 3.62 should not be significant, however it is also possible this variation is due to the 10% variance observed with dosimeter measurements (as given by the error bars). This figure indicates, despite 10% variance in dosimeter measurement, that zinc aluminium trapezoidal influences the erythemal exposure most significantly on the face and chest and fairly significantly for the remaining dosimeter positions, except for the top of the head, back of the head and back of the neck.

4.3.1.5 Cream trapezoidal Winter 2008

The erythemal exposures measured in the winter period are higher than those measured in autumn, however, this could be due to the weather conditions at the time of each measurement. The presence of clouds has been known to increase UV exposure (Sabburg, Parisi & Kimlin 2003; Sabburg & Long 2004; Sabburg & Parisi 2006). In Figure 3.63 the erythemal exposures measured are similar to those received in the autumn period by the pale green coated trapezoidal surface, with the erythemal exposure received by the head form near no wall exceeding the erythemal exposures received by the head forms near walls. By comparing the ratio of erythemal exposure received for the head form near the reflective wall to the erythemal exposure received for the head form near no wall for the two seasons in Tables 3.3 and 3.4 it is possible to determine a seasonal aspect. This has been expressed in the following Figure 4.4 to highlight the difference.

In this figure there is only one ratio in the autumn measurements that exceeds the ratios obtained for the winter measurements (section (a)), and only marginally in some cases. Section (b) and (c) shows that the difference increases only by a small margin. Looking at the daily average for both cream trapezoidal measurements in Tables 3.3 and 3.4, the averages are similar but not exactly the same, with winter ratios definitely exceeding autumn ratios (for the reflective wall to no wall ratio).

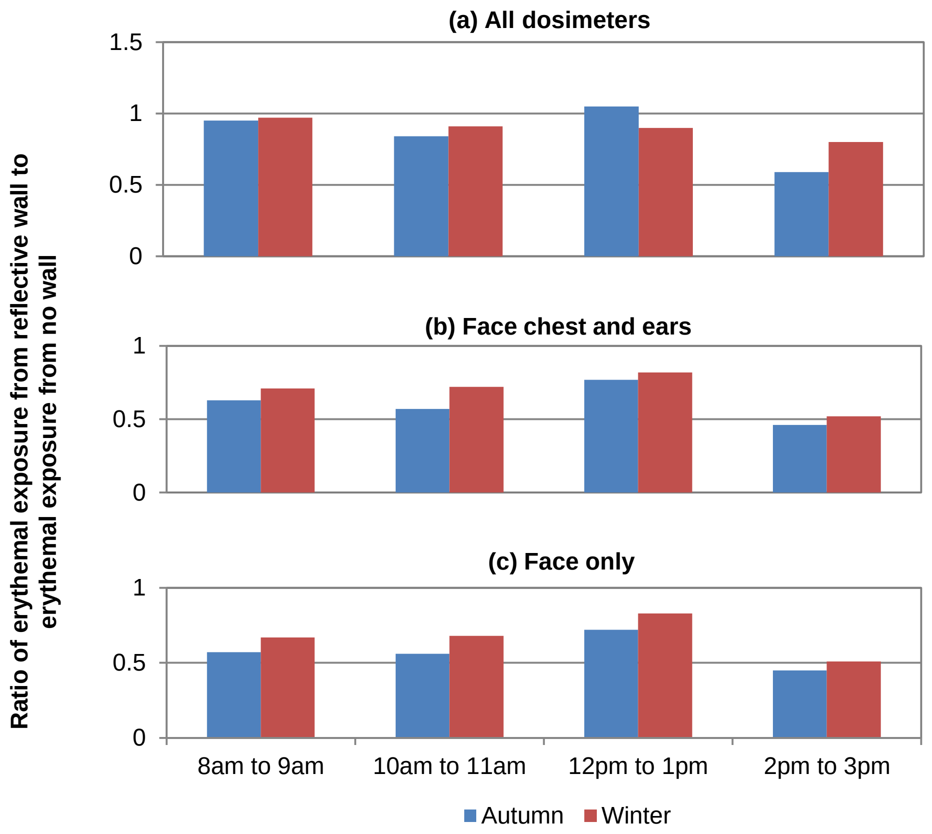

Figure 4.4 – Comparison of the ratio of erythemal exposures from head form near a cream trapezoidal wall to erythemal exposures from head form near no wall.

4.3.1.6 Zinc aluminium corrugated Spring 2008

Figure 3.64 shows the average erythemal exposure for each head form position for non-reflective wall, reflective wall and no wall. The erythemal exposure in Section (a) is comparable to the erythemal exposures received by zinc aluminium trapezoidal in Autumn but with less erythemal exposure in Sections (b) and (c). In general the erythemal exposure received by the head form near a reflective wall appears to exceed the erythemal exposure received by the head form near no wall, but in some cases only matches the erythemal exposure (12 pm to 1 pm and 1 pm to 2 pm) and in one case is less than the erythemal exposure (2 pm to 3 pm) measured near no wall. Looking at Table 3.5, the ratio of the erythemal exposures received by the head form near the reflective wall to the head form near no wall is much less than measurements made for zinc aluminium trapezoidal in autumn.

Figure 3.65 shows the estimated exposures for zinc aluminium corrugated using the exposure estimation equation for the case when the Bentham spectroradiometer was not functioning properly. The graph has a scale on the y-axis simply to highlight the differences between exposure estimation, however at this point it is not possible to be sure of the total exposures received due to the unknown value of the calibration constant. It is possible to compare between estimated head form exposures by calculating the ratios of estimated exposures per head form (and cancels out the calibration constant), presented in Table 3.5 labeled “late spring-early summer”. This has been graphically represented in Figure 4.5 to be visualized more easily. It is visible in this graph that most of the ratio of erythemal exposure on a head form near a reflective wall to erythemal exposure received on a head form near no wall for the earlier spring measurements only marginally exceed the ratios recorded for the estimated exposures in late spring. For section (a) only the hour before midday and the hour interval of 2 pm to 3 pm shows the opposite, however, when considering section (b) and (c) the highest ratios are now observed in these intervals for the early spring measurment. In these sections it is also observed that for some hour intervals that had marginal differences between the exposures, either increase further, or match. The ratios only appear to match for each season’s measurements for 9 am to 10 am and 2 pm to 3pm and are similar for 12 pm to 1 pm. One can conclude that it appears that early spring has a greater influence on increasing erythemal exposures due to a reflective wall than late spring due to larger SZA during the day in early spring compared to late spring.

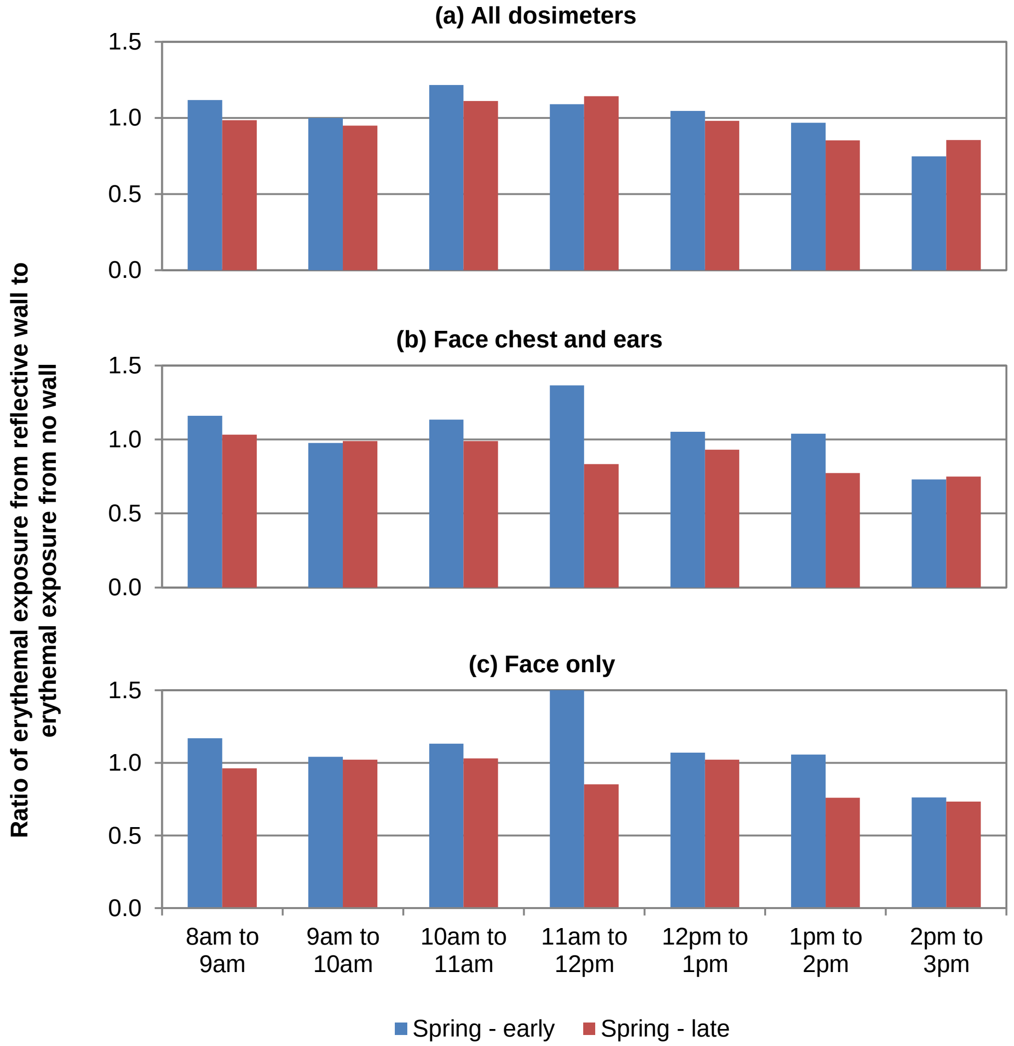

Figure 4.5 - Comparison of the ratio of erythemal exposures from head form near a zinc aluminium corrugated wall to erythemal exposures from head form near no wall for two experiments.

4.3.1.7 Zinc aluminium trapezoidal Spring 2008 and 2010

Figure 3.66 shows similar results to that obtained for the average erythemal exposures presented in Figure 3.64 (zinc aluminium corrugated). The same general form is observed, where in the morning the average erythemal exposure received by the head form near the reflective wall is greater than that received by the head form near no wall, except now there is a shift observed, at 11 am to 12 pm, where the average erythemal exposure received on the head form near the reflective wall is less than the head form near no wall when looking at sections (b) and (c). Again the data in Table 3.5 indicates that the ratios for zinc aluminium trapezoidal are much less, when compared to the ratios received in autumn (Table 3.3). As only one spring measurement for zinc aluminium trapezoidal had been conducted, a repeat of the experiment was carried out in October 2010 to confirm the results found in October 2008 (Figure 3.68). Again we see the same sort of trend in the erythemal exposures. Interestingly the hour of 1 pm to 2 pm does not appear to have the same effect observed as October's 2008 measurements, where the exposures experienced by the head form near the reflective wall is definitely higher than that near no wall for all dosimeter groupings. Figure 4.6 repeats this data in graphical form to emphasise the differences observed. Section (a) shows that the difference between autumn and spring data of the ratio of the average of all the erythemal exposure received by the dosimeters from the reflective wall to no wall, is less than in sections (b) and (c) where there is an increasing difference between the ratios of autumn and spring. Only the hour interval from 1 pm to 2 pm does not have significant differences between the ratios of autumn and spring. The reason for this particular interval not exhibiting the same behavior as the rest of the day's data is not clear, but might be attributed to the SZA and SAA at that time of day. It should be noted that Figure 4.6 has the measurements order arranged according to the time of year: Autumn (May), Spring 2010 (17 & 18 October) and Spring 2008 (28 & 29 October) to see if the time of year is influential within seasons which overall it does appear to be. Overall, the data presented in the spring measurements shows a decrease in influence of erythemal exposure on a head form near a wall of zinc aluminium trapezoidal compared to autumn.

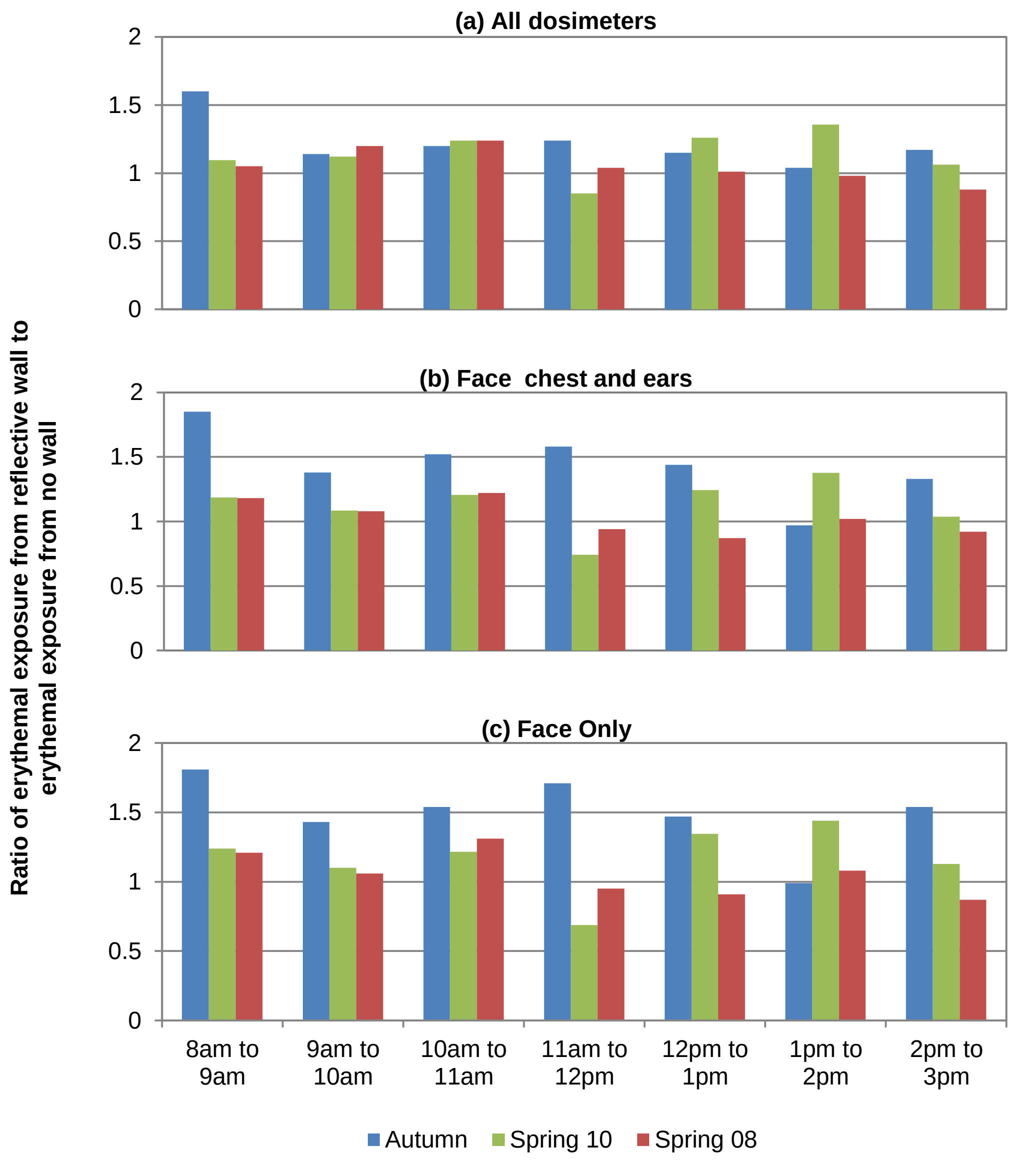

Figure 4.6 - Comparison of the ratio of erythemal exposures from head form near a zinc aluminium trapezoidal wall to erythemal exposures from head form near no wall for two seasons.

4.3.1.8 Dosimeter comparison of Spring 2008

Figure 3.67 indicates there is no significant difference between the influence of zinc aluminium corrugated or zinc aluminium trapezoidal on the dosimeter position on a head form, when the ratio of the exposures from a reflective wall to no wall is averaged over the day. There is one exception, which is indicated by the left cheek position for the corrugated repeat measurement, however this is not observed for the right cheek position, therefore it is possible this is due to an outlier amongst the data.

Averaging the dosimeter exposure ratios for both sets of zinc aluminium corrugated data measurements would appear to match the values measured with the zinc aluminium trapezoidal surface. If the data is broken down into its constituent hourly interval measurements, there is some variation between the exposures received, but these do not appear to follow a particular trend.

4.3.2 Comparison of vertical, horizontal or inclined reflective surface influence on erythemal exposure

4.3.2.1 Zinc aluminium trapezoidal

4.3.2.1.1 North facing

The previous sections have indicated that a vertical surface is capable of influencing erythemal exposure. Reflection from horizontal surfaces has been investigated (see Literature Review) but less so for the influence on erythemal exposure. One of the research questions of this study was to compare the influence of reflection from vertical and horizontal surfaces. Inclined surface reflection has shown to be different from vertical and horizontal reflection (as shown in the spectral reflection investigations) and therefore was also investigated. This is a logical investigation when considering that construction workers are likely to be in the vicinity of all these types of surface orientation, such as when working on flat or inclined roofs as well as near walls.

Figure 3.69 shows the same breakdown of data as used for the vertical surface investigation but in this case the controls have been exchanged for horizontal and inclined surface (35°) in the same reflective surface type. Comparisons in this experiment however, are not as straightforward as in the previous vertical surface study. In this case, the dosimeters remain in the same position on the head form, but the head form itself is oriented differently for each surface (as indicated in the

Methodology). This inherently moves the dosimeter so that different incident angles of direct UV irradiance is likely to influence the same dosimeter position differently (a dosimeter on the upright forehead would be exposed to total irradiance most of the day, whilst the same position on a head form parallel to a horizontal or inclined surface is likely to not have total irradiance influencing it for most of the day, only diffuse or reflected irradiance). The head form oriented parallel to the horizontal surface also was positioned with the head pointing south rather than north, and this may have affected the exposure experienced by the head form. So in this case it is not feasible to compare single dosimeter positions, but only the average to the entire head and shoulders or certain areas of the head. In Figure 3.69, section (a) displays the average over the entire head and shoulders, including dosimeters that are unlikely to be influenced by the surface, which at the same time are going to be influenced differently because of the angle the head form is oriented to relative to the position of the sun. The horizontal surface shows the least overall exposure compared to the vertical surface, and in turn the vertical surface is less overall compared to the exposure from the inclined surfaces. This remains mostly the same for section (b) but in section (c) where the facial area is concentrated on, the inclined surface remains a greater influence, whilst the horizontal and vertical surfaces appear to have approximately the same influence even though they are oriented at right angles to each other. However, the horizontal head form will also shade the surface below it, but it is unclear from this data how the shading has influenced the erythemal exposure, while it appears reflection has influenced the erythemal exposure.

4.3.2.1.2 East and west facing

The results found from orienting the surfaces towards the east in the morning hour intervals, and towards the west in the afternoon hours have some differences to the results found from the north oriented surfaces. In Figure 3.70 section (a) the total dosimeter average over the hourly intervals have similar erythemal exposure values for inclined and vertical during midday and the afternoon, which does not follow the trends observed in some of the morning intervals and in the north facing surfaces. Section (b) shows decreased erythemal exposures observed at midday for the inclined surfaces, but the vertical exposures remain high, and actually higher than the inclined surface exposures. This interval and 2 pm to 3 pm in the afternoon indicate that the vertical surface is influencing the erythemal exposures more than the inclined surface, and this could be due to the SZA although the inclined surface was expected to produce higher exposures received in the hour before midday (which contains solar noon) since the inclined surface is likely to be almost perpendicular to the position of the sun. The only explanation for not observing the higher erythemal exposure for the inclined surface is that it was still oriented towards the east in that interval, and it is during this hour that the sun changes the SAA by moving from the east to the west part of the sky's hemisphere. If the sun is more into the west in this hour interval, it may decrease the exposure influence from the inclined surface. From that hour onwards into the afternoon, both the inclined and vertical surface appear to have the same influence on the face, chest and ears. Looking at section (c) the erythemal exposures in the interval before midday has changed again where the influence of the horizontal surface now exceeds the inclined surface, and this can be probably be explained by the same reasoning as given for section (b) where the horizontal surface is at an optimum point for reflecting irradiance compared to the inclined surface. The relationship between the three surfaces does not appear to be consistent across the hour intervals in the day, which might suggest that the surface that causes the most influence is dependent again on the position of the sun in the sky (SZA and SAA).

4.3.2.2 Pale green trapezoidal

In Figure 3.71 section (a) the influence of a pale green trapezoidal vertical surface appears greater than the horizontal or inclined surfaces. Looking at the dosimeters that are more likely to be influenced by each surface in section (b) we see the comparative influence is much less and in the two hour interval before midday the influence of inclined and vertical surfaces are similar. Outside this time period it appears that the vertical surface has more influence than both the inclined and horizontal surface, and that each of these two surfaces have similar erythemal exposures. In section (c) there does not appear to be much difference between the inclined and vertical surface erythemal exposures compared to section (b) but the erythemal exposures received by the face for the horizontal surface are slightly lower. This may be due to the orientation of the face away from direct irradiance, the face is shaded and as a result the sheeting underneath is also shaded, with only the outer edges of the sheeting likely to reflect direct irradiance.

4.3.2.3 Comparison of surface type reflection

The erythemal exposures measured from the pale green trapezoidal sheeting is less than half of the erythemal exposures experienced by the head forms near zinc aluminium trapezoidal sheeting. Table 3.7 compares each surface orientation to each other for each surface type and direction. Pale green trapezoidal is noticeable by its higher ratios than those obtained for zinc aluminium trapezoidal (north, east and west), but this can potentially be explained by the fact that much lower exposures are obtained from pale green trapezoidal compared to the zinc aluminium trapezoidal, and as a result, a slight difference in exposures may result in proportionally higher ratios. The ratios are particularly high when comparing the pale green trapezoidal vertical surface to the pale green horizontal surface. What this might indicate is that the shaded area on the pale green trapezoidal surface is even less effective at reflecting diffuse UV than direct UV radiation. Zinc aluminium trapezoidal may not have such high ratios due to the surface difference (smooth and shiny compared to less smooth and less shiny) which may contribute to more effective reflection for diffuse UV radiation. The topic of direct and diffuse reflection will be discussed further in later sections. The other explanation may go back to the original vertical reflection experiments for pale green trapezoidal, where it was shown that the erythemal exposure from pale green trapezoidal was not significantly influenced compared to zinc aluminium trapezoidal. The vertical position of the head form would contribute to the maximum erythemal exposure due to lack of shading occurring due to the surface direction. Both inclined and horizontal surfaces undergo some shading due to the "act of leaning over" the metal sheeting, and would naturally lower the erythemal exposure experienced. Therefore, even though the pale green trapezoidal is not highly reflective, at a vertical orientation, the exposure received by the head form near the pale green vertical surface would appear like a head form vertically orientated near no wall, but the other orientated head forms would not and therefore naturally have less exposure. The important features in Table 3.7 are observed in the daily averages, where it is observed that the vertical to inclined ratio for zinc aluminium trapezoidal (all dosimeters) is around the value of one for most dosimeter groups and only drops for the facial dosimeter group, indicating that the inclined surface has a slightly higher influence than a vertical zinc aluminium surface, whilst the vertical surface has more influence than the inclined for the pale green trapezoidal. The vertical to horizontal ratio for zinc aluminium trapezoidal is greater than one and is likely attributable to the shading caused by the head form over the horizontal surface receiving lower exposures. The ratio for pale green trapezoidal exceeds a ratio of two which would be due to the same reasoning for the zinc aluminium trapezoidal. The inclined to horizontal ratio follows the same trend for both surface types where the erythemal exposure received by the head form positioned near the inclined surface is higher than that received by the head form near the horizontal surface, also due to the effect of shading.

4.3.3 Influence of reflective vertices on erythemal exposure

4.3.3.1 Zinc aluminium trapezoidal

The erythemal exposures in Figure 3.72 for the vertices (or corners) appear fairly similar to the erythemal exposures measured for the wall exposures measured in Autumn 2008 for zinc aluminium trapezoidal (Figure 3.59). The erythemal exposures measured in section (a) Figure 3.72 are higher erythemal exposures than those in section (a) Figure 3.59. Also, the erythemal exposures for the reflective wall in the 10 am to 11 am interval and the 12 pm to 1 pm interval are higher than that for the 11 am to 12 pm interval (Figure 3.72). A suggestion for this variation is the way the corners are set up. In the morning, the corner is composed of a north facing and east facing wall, whilst in the afternoon the corner is composed of a north facing and west facing wall. In the interval 11 am to 12 pm, the sun reaches its solar maximum from the eastern side and moves into the western side of the sky. This may cause less direct irradiance to fall on the head form and the east facing wall, and possibly block irradiance due to the east facing wall and slightly reduce the erythemal exposure. At 12 pm to 1 pm the corner is changed from east facing to west facing and therefore should not be blocking any UV irradiance and resulting in slightly higher erythemal exposures compared to the previous interval. In section (b) the interval of 10 am to 11am still has a proportionally higher erythemal exposure compared to the other hour intervals, which is maintained in section (c). The differences between the erythemal exposure from the reflective wall is proportionally higher compared to the controls and if Table 3.3 and Table 3.8 is compared for the facial dosimeters for the reflective to no wall ratio, we can see some ratios are comparable while others are not. Figure 3.74 shows the comparison between the measurements made for the wall in Autumn 2008 and the corners in Autumn 2009. Section (a) of Figure 3.74 shows that all dosimeters tend to have a higher average erythemal exposure from the reflective corner than for the wall, and since the head form has two sides around the head form, this is a logical outcome. Even dosimeter positions such as the back of the head or neck are potentially going to have their erythemal exposure influenced, while the dosimeters on the back of the head form near the wall will not as shown in Figure 3.74. In this figure, for the cases where the ratio is below one for the intervals over the day, the corners have lifted the ratio above one, indicating significant influence. However, if smaller body areas are concentrated on, then the presence of the corner is not so important. Section (b) shows the influence of the corner is now matched by the influence of the wall for some of the hour intervals, and in section (c) only the two hour intervals flagging the solar noon interval significantly influence the erythemal exposure to the face compared to the wall. In the last afternoon interval the wall has more influence than the corner. When looking at each specific dosimeter position in Figure 3.75, there is specific influence to some body sites, but surprisingly not for the dosimeters located at the back of the head form. Instead, the dosimeters placed on the cheeks and ears have the most influence from the presence of the corner. The remaining dosimeter positions appear similar for both corner and wall except for the forehead and top of the head, but as both these dosimeter positions are also influenced by direct irradiance, it is difficult to tell if this is due to the presence of a corner, or if the weather conditions on each experiment day were different. The ozone measured during wall experiment range from 255 DU to 259 DU, compared to the ozone measured during the corners experiment which ranged from 255 DU to 266 DU, which is not a large variation. Due to the nature of ozone, UV radiation reaching the earth's surface on a day with higher recorded ozone columns will not exceed the UV radiation reaching the earth's surface on a day when lower ozone columns were recorded. Therefore, it is unlikely that ozone is a significant influence on the exposures received due to a wall or a corner. The measurements were carried out earlier in the autumn season than the wall measurements in the year before, which would mean larger SZA present for the wall measurements. In addition, the corner measurements were carried out under greater cloud coverage, therefore reducing direct irradiance incident on the corner surfaces, which combined with the smaller SZA could indicate that reflection from a corner may be higher on a clear day and later in the season. That suggests the slightly higher erythemal exposures obtained on the head forms on the cheeks from the corner measurements could be significant.

4.3.3.2 Pale green trapezoidal

Figure 3.73 shows the same break down of erythemal exposure measurements as that given for zinc aluminium trapezoidal. With this surface type, there is little difference in its influence and that of the non-reflective corner and no corner for most of the morning in section (a). It is clear that there are slight variations between the three erythemal exposures but not a large variation. In the hour preceding midday and the two afternoon intervals, the head form located near no corner received the highest erythemal exposures, indicating that the presence of the pale green corner was having nearly the same effect as the non-reflective corner. Therefore, it might be assumed that the pale green trapezoidal surface in this configuration does not contribute to increasing erythemal exposure, and may in fact reduce erythemal exposure. The same pattern is observed in sections (b) and (c) for the morning as well as the afternoon, thereby indicating that this surface type in a corner configuration is unlikely to increase erythemal exposure beyond that of what might be received when no corner structure is nearby. Figure 3.76 compares the ratios between the reflective corner and no corner of Table 3.8 (Autumn 2009) to the same ratios received for the wall in autumn 2008. In section (a) we only see the hour preceding midday for the wall significantly exceeding the ratio for the corner, although previous discussions indicated some doubt as to whether this ratio has not been adversely affected in some way. In section (b) the ratio difference for this hour interval has decreased, but we then also see that most of the afternoon hour intervals have higher ratios for the wall than for the corner and this is similarly reflected in section (c). This figure suggests (as previously stated) the pale green trapezoidal is not as effective at influencing erythemal exposure, and that corners may in fact block further UV irradiance due to its configuration. A wall constructed of the same sheeting shows more influence, because the head form is more exposed to UV irradiance with a more open area than a corner.

4.3.4 Influence of non-metallic UV reflecting surfaces

4.3.4.1 White painted fibro board

The spectral reflection data presented earlier in the chapter suggested that white painted fibro board had some UV reflection occurring. As the surfaces were part of existing structures, the non-reflective surface was created by hanging a large piece of black felt across a section of the building wall, and the head form was situated in front of the cloth. As both the reflective wall head form and the non-reflective head form had to be lifted off the ground to be situated in front of the surface (the building was on stilts), so too was the head form near no wall lifted off the ground, to give similarity to the dosimeter positions on the head form. Figure 3.77 in section (a) shows the head form near the reflective wall receiving less than the head form near the non reflective wall. This would indicate that in fact the reflective wall is less reflective than the non-reflective wall. Looking at the dosimeters located on the front part of the body (facing the wall) in section (b) this trend is consistent nearly all day with the head form near the reflective wall receiving the least erythemal exposure, and in section (c) at larger SZA, the head forms receive no erythemal exposure at all. This clearly indicates that shading would be significant at these hours of the day, and that the reflective capability of this surface type is extremely low in the UV spectrum. It is interesting to note that the head form near the non-reflective wall (black felt) received higher erythemal exposures than the head form near the white painted fibro board. It is clear from this experiment that people placing themselves in a situation such as this incurs greater erythemal exposure from being outside in a sunny area, and suffers no erythemal exposure increase from the nearby building surface, and in fact can reduce their erythemal exposure.

4.3.4.2 Red brick

The red brick wall was a part of a recreation complex consisting of a gym and indoor and outdoor courts and a crèche. The building is not surrounded by gardens or eaves, even though the children of the crèche are brought outside regularly. Only recently has the crèche area added shading. Young children may have heights that are comparable to the head form heights, so this part of the study is interesting in terms of exploring influence on children as well as adults. Section (a) of Figure 3.78 indicates that the erythemal exposures of the three situations (non-reflective, reflective and no wall) are fairly similar except in the afternoon when the head form near no wall exceeds the erythemal exposure for both the head forms near the non-reflective wall and reflective wall. These two latter head forms have very similar erythemal exposures across the day. In section (b) the erythemal exposures to the front of the body are significantly reduced, and of course the head form near no wall has the highest erythemal exposures. In section (c) there is little difference to the erythemal exposures compared to section (b) and shows that the red brick does not cause higher erythemal exposures compared to no wall, and are only marginally higher compared to a non-reflective wall. This indicates that red brick has no significant influence over increasing erythemal exposure, but does block some erythemal exposure. A person in the open receives more average erythemal exposure than a person near the wall.

4.3.4.3 Comparing the two non-metallic surfaces

Table 3.9 shows the ratios of average erythemal exposure for the head form locations and time intervals, and it clear by considering this data that the white painted fibro board has significantly less reflective capability than the red brick surface, and compared to zinc aluminium trapezoidal, has little or no influence in increasing erythemal exposure. This is in direct contrast to the spectral reflection data analysed earlier, which indicated quite high reflection in the UVB waveband. Previous discussion about this topic has considered the effect of diffuse UV radiation but the reason for the discrepancy is not clear.

4.4 Quantification of relationship between horizontal and vertical reflectivity

4.4.1 Zinc aluminium trapezoidal

For all the erythemal exposure experiments, spectral measurements of each surface orientation and type were measured. There was no shade affecting the measurements, therefore, these measurements are maximum spectral reflection measurements (but not accounting for shading caused by a person or head form's body). Unfortunately, there were not as many scans taken of the horizontal and inclined surfaces as there were vertical surfaces, so there are only three days of spectral measurements that can be used for this analysis. For zinc aluminium trapezoidal, the days of measurement used for this analysis are 27 April 2009, 14 August 2010 and 19 October 2010. The erythemal weighted ratio for each reflection measurement was calculated (as described in Section 4.2.3.2.1) for each surface inclination and correlated according to SZA and SAA. In Figure 3.79, there is some trend visible relating the vertical and horizontal erythemal reflectivity. Forcing the trend line through zero, it is apparent that this trend suggests that vertical and horizontal erythemal exposure (when not shaded) should be equivalent to each other. There are however a number of outliers, and further data would need to be obtained to confirm this. Figure 3.80 indicates a very definite trend between vertical and inclined erythemal reflection. This trend line has not been forced through zero due to the significant reduction in R^2 this forcing produces. This trend line specifically highlights the erythemal reflection capacity of inclined zinc aluminium trapezoidal is higher than the vertical erythemal reflection capacity for the lowest of reflection values. However, as the reflective capacities of each orientation reach the higher reflective values, they begin to approximate each other. To confirm this behavior the data was broken down into groups of SZA. For small SZA, the vertical erythemal reflection is half that of inclined erythemal reflection, whilst in the SZA range of 40° to 49° the inclined erythemal reflection is approximately 50% more than the vertical erythemal reflection and this seems to carry over to the SZA range of 50° to 59°. At the highest SZA the erythemal reflections start to approach similar values.

4.4.2 Pale green trapezoidal

Surprisingly the erythemal reflection capacity of pale green trapezoidal seem to reach high values, as high as 0.6, even though the erythemal exposure measurements indicate the exposure is certainly not influenced by the same magnitude as these high reflections. Figure 3.81 shows that the vertical and horizontal erythemal reflection is mostly equal provided no shading is evident. Figure 3.82 also shows that the inclined erythemal reflection approximates the vertical erythemal reflection as well. Looking at the SZA grouping it seems that from 50° and higher the reflection appears to be very high. Even at the range of 40° to 50° there are reasonably high ratios that are as high as reflection values in the zinc aluminium trapezoidal surface type. This however does not correspond to the erythemal exposure measurements previously taken. What it could mean is that the ambient UV irradiance is more influential than any reflections occurring from this surface type and must therefore be taken into consideration.

4.5 Establishing UVI factors

Establishing a UVI factor for surface types requires that UV exposure measurements have been carried out for the surface type in question. This now limits the UVI factor calculation to surfaces which had exposure measurements carried out, including zinc aluminium trapezoidal, zinc aluminium corrugated, pale green trapezoidal, cream trapezoidal and the white painted fibro board and red brick. Out of all the surface types investigated for UV exposure influence, the metal surfaces had significantly higher influences than the white painted fibro board or red brick. This section will concentrate only on metallic surfaces, as the effect of white painted fibro board or red brick tends to actually be UV exposure reducing rather than any other effect observed.

In order to produce a UVI factor, the UV Index at the time of the measurements was required. Fortunately, the UV Index was available from regular five minute interval measurements made by a UV-Biometer located nearby on the University Campus. The UV Index is calculated by taking into account the calibration of the system then applying the UVI formula as specified by McKenzie & Renwick (2002). Each five minute interval measured by the UV-Biometer then has a corresponding UV Index number. As the exposure measurements used intervals of 60 minutes (one hour), the average UVI value was determined for each hour of exposure. For each surface type, and for each grouping of dosimeters that has been used previously, the average erythemal UV exposure values recorded by the dosimeter groups were plotted against the average UVI value recorded. Then for each head form type (reflective wall, non-reflective wall and no wall) the function of the trend line showing the line of best fit through the data was determined using the Excel trend line feature. The figures of all these plots can be found in Appendix 7.3. In Table 3.10, the coefficient of the slope of the resulting trend line functions has been summarized for the total average erythemal UV exposure of all dosimeters per head form, as well as the corresponding R^2 to indicate the fit of the data. The functions of the trend lines had the following imposed on them: the y-intercept was forced through zero (as UVI = 0 should correspond to zero exposure), and the trend line was linear. In the charts produced for the zinc aluminium surfaces, the trend lines were clearly linear, and any other sort of function would increase the R^2 but not necessarily change the shape of the trend line. However, the smaller the group of dosimeters used to calculate the erythemal UV exposure (such as the face group of five dosimeters) the less linear some data values trends became (supported by some negative R^2 values). The same lack of apparent linearity was also observed for paint coated surfaces but was not consistent across the dosimeter groups. Despite this observance, the trend line functions were restricted to the limitations described, in order to compare between wall types, which Table 3.10 displays. The observance that the ratio of the erythemal UV exposure incurred near a zinc aluminium surface and no surface, decreases for warmer seasons is still mostly supported here. Autumn 2008 has higher ratios compared to spring measurements, whilst between the spring measurements, the 2010 measurements were taken earlier in spring than the 2008 measurements, showing a definite decrease in the ratio. The early spring measurements for zinc aluminium corrugated do not follow this pattern, with a higher ratio than autumn, however, the early spring data was made up of data that had at least a week separating the days of measurement, with cloud cover present, which may contribute differently to reflective influences. The corner measurements for zinc aluminium trapezoidal with higher ratios is supported by the fact that those measurements were carried out earlier in autumn 2009 than the wall measurements in 2008. The other surface that does not follow the seasonality condition is the cream trapezoidal ratio for autumn 2008 with slightly higher ratio rather than smaller ratios compared to winter. The issue with the paint coated surfaces is that this difference is only 3% and may not be considered a significant difference since the dosimeter measurements have a 10% associated error. In addition, the difference between the reflective qualities of the surface itself may change its ability to influence erythemal UV exposure. Essentially, these ratios are simply showing similar values as those collected and reported in Sections 3.3 to 3.3.7.

From this data it was then wondered whether any of the surface types really differ in their ability to reflect UV radiation, so all the surface types of a zinc aluminium finish were plotted on the same chart (Figures 7.84 to 7.86), and the same for the paint coated sheets (Figure 7.87 to 7.89). Overall the spread of the data suggested that each surface type investigated (reflective wall, non-reflective and no wall) generally followed the same trend when plotted against the corresponding average hourly UVI. The coefficients of the slope of these trends are summarized in Table 3.11 for the different dosimeter groupings (charts in Appendix 7.3). This table again shows that if a particular area of the body is focused more and more closely, the ratio investigated changes – increasing for a zinc aluminium finish and decreasing for paint coated finish.

From this data it is apparent that there is no simple method of estimating erythemal UV exposure (if the areas of the body that might be exposed are not well known for a study's purposes). However, looking at the relationship between erythemal UV exposure and average UVI, for a surface type, it was considered that there might be a simple way to estimate erythemal exposure. Figure 3.83 (zinc aluminium finish) and Figure 3.84 (paint coated finish) display the data spread and trends of the data. The trend lines fitted are quadratic polynomials, which is not a simple relationship. If necessary, a linear function could be forced through the data, but the use of the polynomial function is more useful in that it clearly displays the tapering off, of the influence of the reflective surface at higher UV Index values. This will be important for the next area of discussion.

4.6 Resolving contributions of direct and diffuse UV radiation for effective reflectivity measurements

The proportion of diffuse to direct irradiance changes throughout the course of a day, and will change from season to season. When the sun is at a large SZA, the proportion of diffuse to direct irradiance will be much higher than at a smaller SZA. This is due to the path UV irradiance travels through the atmosphere, which is longer for larger SZA and shorter for smaller SZA. The longer the path the UV irradiance travels, the more likely UV irradiance will encounter scattering or absorbing media, thus producing diffuse UV irradiance.

Figures 3.85 and 3.86 display the diffuse spectral reflection measured from vertical, horizontal and inclined surfaces with different coatings and surface profiles. For zinc aluminium coated surfaces the spectral reflection appears to be wavelength independent for part of the UVB waveband and all of the UVA waveband. The vertical surface appears to have lower diffuse spectral reflection than horizontal or inclined, while the trapezoidal version appears to have a lower diffuse vertical spectral reflection than the corrugated. For paint coated surfaces (cream coloured) the spectral reflection is less independent, with reflection increasing in the UVA waveband as it approaches the visible spectrum. There is not a lot of variation between the diffuse spectral reflection from vertical, inclined or horizontal surfaces for paint coated surfaces.

Figure 3.87 compares diffuse spectral reflection measured from zinc aluminium trapezoidal vertical surface to total spectral reflection measured on the previous day, with both measurements almost identical in SZA and SAA. The diffuse spectral reflection appears greater than total spectral reflection, although when put into context in Figure 3.88, it is apparent these differences rely on total and diffuse UV irradiance present in the atmosphere. If the reflected diffuse spectral UV irradiance was relative to total UV irradiance instead of diffuse UV irradiance, the ratio of diffuse spectral reflection would be then lower than that for total spectral reflection, but not by much. This is shown by the green line in Figure 3.87, which indicates that diffuse reflection may be responsible for at least half of the total spectral reflection occurring from zinc aluminium trapezoidal.

Figure 3.90 indicates that the position of the sensor with respect to the surface and sun may be just as important as surface type. This relates to the discussion on total UV irradiance detection earlier in this chapter. However, it is now the position in which *reflected* UV irradiance may be measured, as well as the position of the sensor from which total UV irradiance is measured. Figure 3.90 displays the ratio of the reflected irradiance to total UV irradiance, for two reflected UV irradiance measurement orientations. The sensor inclined at 45° indicates a much higher reflection ratio than the sensor oriented normal to the surface. At first it is tempting to suggest that the sensor orientation places it in a situation in which direct UV irradiance from the sun may be striking the sensor, and thus influencing the ratio. However the shape of the spectral reflection is similar to the measurements with a horizontal (or normally positioned) sensor. Compared to the very first measurements made in this entire study, where additional direct UV irradiance from the sun struck the sensor as well as reflected irradiance in a reflection measurement, the spectral outputs obtained were significantly different in shape as well as intensity. Despite the possibility that direct UV irradiance is striking the sensor, it is likely that the surface area exposed to the direct UV irradiance would be minimal so that the measurement of direct UV irradiance would be negligible as suggested in the discussion on sensor orientation. Thus, it is possible that the specular reflection capability of this surface type significantly influences reflection of UV radiation. A figure used by Nayar, Ikeuchi & Kanade (1991) reproduced in Figure 4.7 helps explain what is occurring.

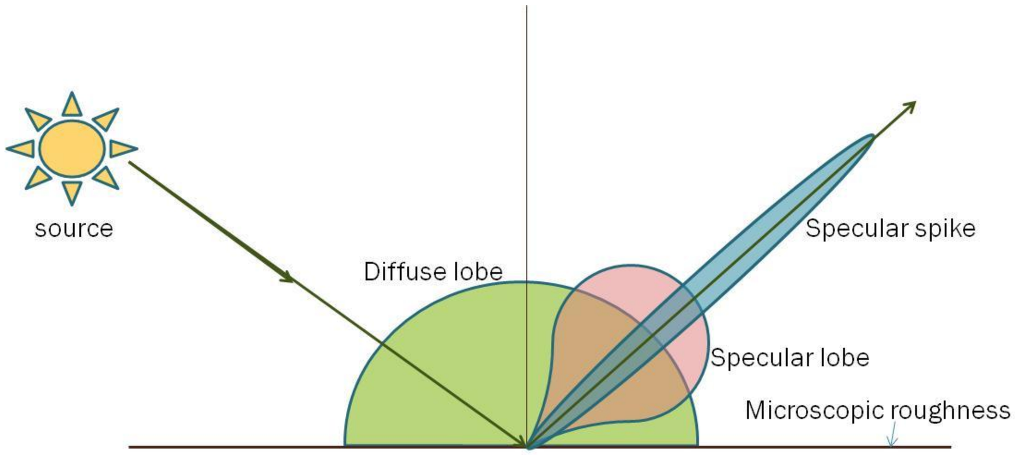

Figure 4.7 – Reproduced: *Figure 16 from*: Nayar, SK, Ikeuchi, K & Kanade, T (1991) Surface Reflection: Physical and Geometrical perspectives, IEEE Transactions of Pattern Analysis and Machine Intelligence, 13(7), pp. 611-634.

From the literature review the nature of reflection was essentially considered as a combination of diffuse and specular reflection. In research fields where computers are used to create images that account for all types of reflection, the above diagram is used to create understanding of the physics of reflection (Nayar, Ikeuchi & Kanade 1991). It would seem reasonable then to use the same diagram to try and understand what is happening in UV reflection and some of the data presented in this study appears to confirm this.

The diffuse lobe uses the assumption that some or all reflection is isotropic from a Lambertian surface. The specular lobe shows a concentration of reflected UV irradiance which is dependent on the angle of incidence of the irradiance, although the reflection angle is variable, and this is due to the surface itself at the micro scale. The specular spike is not quite so important in the case of UV reflection, since it represents mirror-like reflections, where the intensity and direction of the incident irradiance is only minimally affected by the reflection process. In Figure 3.90, the movement of the sensor from perpendicular to the inclination of the surface for reflected measurement, to an angle 45° from the perpendicular, greatly increases the intensity of the reflection being measured but not the shape. It would appear that for this surface type, that the sensor may have been moved into the specular lobe area of the reflective surface. If the sensor was previously held perpendicular to the surface, it is very likely it would have been on the outer edges of this lobe or maybe not even within the lobe. Instead it may have been only recording the diffuse lobe.

Is the diffuse lobe really a diffuse lobe? Is it possible that it is only diffuse UV irradiance rather than reflected diffuse UV irradiance? Figure 3.89 represents the investigation of this question, although there were not many opportunities to explore the question experimentally. Using reflection data made on a day where there was enough cloud to completely obscure the sun (about 60 to 70% total sky cover), reflection measurements from different coated metal surface types and diffuse measurements made (with the sensor positioned in the same fashion as the reflection measurement just not near any wall) were considered. The data from the zinc aluminium coated surfaces were considered (Figure 3.89 a & b), and at first glance it appeared that the attempts to measure reflected diffuse UV radiation had failed, as the standalone diffuse measurements (relative to total UV irradiance) appeared to be exactly the same as the diffuse spectral reflection measurements. However, when the paint coated surfaces were considered, a different scenario emerged. In Figure 3.89 (c & d), the diffuse spectral reflection measurements proved to be much lower than the diffuse measurements. If the zinc aluminium finished surfaces was not reflecting diffuse radiation, then the diffuse spectral reflection measurements of the zinc aluminium finish would be the same as the paint coated surface, which is not the case. Instead, it can be derived from this data that there is potentially diffuse reflection occurring through the process of deduction.

If the paint coated surfaces have a lower ratio than the diffuse measurements, it must mean that some diffuse UV radiation is being blocked from the sensor. With the zinc aluminium finished surfaces, the same blocking effect should be occurring, but if the surface is also reflecting diffuse UV radiation, it is possible that the blocking and reflecting mechanisms are equating to the total diffuse UV radiation present already. If we assume that a paint coated surface is a poor diffuse UV reflector, then this would account for the differences observed between the zinc aluminium coated finish measurements and the paint coated surface measurements.

Unfortunately there does not appear to be enough data to be able to calculate the separate diffuse and direct UV reflective capabilities of these surface types. However, is there a need to know how the breakdown of UV reflection between direct and diffuse UV occurs? One could argue that direct UV radiation never occurs without the presence of diffuse UV radiation, and therefore diffuse reflection must be taken into account for any total reflected UV irradiance measurements (such as the measurements conducted in this study). Therefore one can conclude that understanding the breakdown of direct and diffuse UV radiation as completely separate entities is not important, but knowing that they both contribute to the changing reflective capabilities of some surfaces is important. Therefore, the analysis carried out in this study, greatly improves the understanding as to why reflection varies, because it has been better characterized by considering the effects of specular and diffuse UV reflection. In addition, many modeling systems do not account for variable UV reflection in urban environments. Using the knowledge obtained here, such as determining if specular or diffuse reflective surfaces will affect the areas of interest and therefore affect the UV reflective properties, modeled systems that predict UV exposure and monitor UV irradiance can be improved.

5 Conclusions

Lack of information about reflection from non-horizontal surfaces motivated this study into understanding reflection from natural, and more importantly, man-made surfaces. A number of previous assumptions have been discovered throughout this study, including assumptions about albedo, its definition, and the assumptions on how reflection occurs. From analysis of the literature review and the preliminary data collected, it appears that the concept of albedo is an inaccurate description of reflection occurring from non-horizontal surfaces, and does not account for the nature of reflection occurring when considering different factors such as surface type, and the position of the sun in the sky, and even the positions of measurement tools used. Therefore, albedo should not be used to quantify reflection from non-horizontal surfaces. Importantly, as a result of exploring the objectives for this study, methods have been developed to account for these factors. These include developing a fully characterised method for measuring reflection from vertical and inclined surfaces that can be compared to reflection from a horizontal surface, and developing a method for measuring personal UV exposure to account for reflection from vertical, inclined and horizontal surfaces. The data obtained from these methods have been analysed and summarised in the following conclusions according to the research objectives outlined in the Literature Review.

5.1 Quantification and analysis of reflection due to vertical surfaces

Reflection from a vertical surface can differ from the reflection measured from a horizontal or inclined surface, and this will depend on the solar zenith angle of the sun, the orientation and inclination of the surface, the distance of the sensor from the surface, and the surface type itself. These variables have been observed to affect reflection from man-made surfaces such as sheet metal used in the construction of urban residential and industrial buildings. These variables are important because of the nature of the surface itself. A broad variety of reflection measurements have been made from some of the most common types of building materials, in order to establish the total reflective capacity of a surface, and this has been done both using a spectrally capable device and an analysis of total exposures (presented in Conclusion 5.3). Due to the range of factors that affect the reflective capability of a man made surface, it is therefore more difficult to ascertain a single value that can express the total reflective capacity of a particular surface. The quantities that have been measured have been recorded here in this study. When the data collected for reflection from metal sheeting is averaged for a particular season and time of day, there is one feature that stands out as being particularly significant, and that has been highlighted in Figures 3.50 and 3.51, in which the coating applied to the metal surface dictates the reflective capability of a metallic surface. Steel coated with zinc and aluminium is more reflective than steel coated with a paint or coloured surface (including thermal paint coatings), by up to twice as much across the UV spectrum. A galvanized (zinc coated steel) surface was also investigated and found to have very high reflection capability. Other surfaces types including glass, white fibro board, brick and transparent plastic have lower reflective capacities. These latter surface types were only briefly investigated in comparison to the thorough investigation of metal sheeting used in construction, therefore, it is somewhat difficult to apply an effective ranking system that accounts for all variables equally. From the data collected it is clear that there are quantifiable differences between reflection measured from horizontal, vertical and inclined surfaces if they are instantaneous measurements made from metallic surfaces. If the data is averaged over time, similarities are then observed between horizontal and vertical surfaces, however inclined surface reflection generally exceeds either vertical or horizontal reflection measurements if the sun is positioned perpendicular to the inclined surface.

5.2 Analysis of relationship between vertical and horizontal reflection

There appears to be a direct relationship between the vertical and horizontal reflection from a metallic surface. This relationship was determined by taking spectral reflection data and converting it to an erythemally weighted reflection ratio and sorted according to SZA and SAA. Reflection from vertical and horizontal surfaces was found to be almost equivalent when considering SZA values that are not extreme (very low or very high). This is true for both zinc aluminium coated metal sheeting and paint coated metal sheeting. Relationships were also found for vertical and inclined surface reflection, and in the case of zinc aluminium coated metal sheeting, the relationship ranges from inclined reflection being almost twice as much as vertical reflection (at low SZA) to equivalent reflection (at high SZA).

5.3 Quantification of the biological effect due to influence from vertical surfaces

From the surfaces investigated a selection was used to quantify the potential biological effect due to reflection from vertical surfaces, including the zinc aluminium coated surfaces, pale green and cream paint coated surfaces, white fibro board and red brick. Other surface factors investigated also included the effect of a corner, and horizontal and inclined surface influence. This was investigated with measured UV exposure using the method of dosimetry. The influence of a reflective wall was accounted for by comparing against exposures measured simultaneously from a non-reflective wall and no wall at all. From the measurements made, zinc aluminium coated surfaces are the most effective at increasing UV exposure received by an individual with the highest increases in erythemal exposure observed at 50% in localised body positions and 20% for average body erythemal exposure. These measurements were obtained in cooler seasons.

However, the other surfaces mentioned were mostly influential by reducing UV exposure not by reflection, but by proximity. The data was quantified using erythemal UV exposure measurements. Initially, vitamin D_3 UV exposures were also calculated, however, it was soon noticed that the proportions between erythemal and vitamin D_3 weighted exposures from the same head forms were similar and it was considered unnecessary to express the same data twice.

The influence of a reflective wall on UV exposure is also variable with season, which is due to the ranges of SZA covered in a season. In warmer seasons, the influence of a reflective wall is diminished compared to the higher ambient UV measurements present, and decreasing specular reflection compared to diffuse reflection on the surface, whereas in cooler months the influence of the reflective wall is increased, and can potentially cause UV exposure levels to total to values higher than recommended exposure limits due to the increased specular reflection from the position of the sun in the sky.

5.4 Calculating a UVI factor

A UVI factor for the surface types explored for UV exposure measurements was calculated, and found to be variable when considering nearby structures, exposure areas on the body and surface types. Of course, the UV exposures measured were naturally dependent on the corresponding UVI. The factors calculated were similar to ratios obtained when comparing the UV exposure recorded for a reflective surface, non-reflective surface and no surface. It was also found that a plateau was present. With lower UVI values the UV exposure increased with increasing UVI, but would start to plateau at much higher UVI values. Relationships were determined for erythemal UV exposures measured due to reflective surface influence according to different body areas.

5.5 Accounting for the direct and diffuse UV components in UV reflection

It was found that direct and diffuse UV reflection can be different for the same surface type. Through reasoning from information from the reviewed literature, it was determined that the changing reflection due to a variety of factors is due to the difference between direct and diffuse UV reflection occurring differently on the same surface, where direct UV reflection behaves much like Fresnel's law of reflection as compared to diffuse UV reflection which behaves according to Lambert's Law. It was established indirectly that zinc aluminium coated surfaces reflect diffusely to some degree, but it was not fully established if paint coated metal sheeting could reflect diffusely effectively. However, even if a surface reflects only direct UV radiation, this accounts for the variability observed in UV reflection from man-made surfaces since Fresnel's Law dictates that the reflection is dependent on the incident radiation. At this stage it is uncertain if the proportions of diffuse radiation to direct radiation also contribute to intensity of diffuse UV reflection.

5.6 Future Directions

Obtaining data from all seasons in the year would be useful to confirm the behaviour of reflection from man-made surfaces in vertical positions. This may be a difficult task since changes in weather can make it difficult to obtain data without confounding factors. Data collected year round could also contribute to establishing monthly averages for the entire year. Year round data could also be useful in establishing if there are specific times when the average reflection from vertical surfaces observably changes from cooler seasons to warmer seasons, thus identifying key times of year that would be important to outdoor workers.

In addition, more diffuse reflection measurements would increase knowledge about diffuse reflection. This will allow determination of whether diffuse reflection is independent of SZA (although when the sun is obscured one would assume that it must be). However, is diffuse reflection under an unobscured sun the same as under obscured sun situations? Techniques to make these measurements would need to be developed. At the same time, the proportion of diffuse UV radiation to direct UV radiation could be explored to consider if changing proportions of these quantities could contribute to changes in intensity of diffuse UV reflection.

A useful future development could be analysing the data also obtained in the visible spectrum and determining if reflection in the visible spectrum can be used to predict the reflection in the UV spectrum. If a relatively simple relationship could be determined, a tool could be developed to help a person who is regularly exposed to high levels of UV radiation (such as a construction worker) determine if they are in the vicinity of a UV reflector without requiring extra equipment.

In conjunction with this, it is clear that recommendations should be made to appropriate authorities governing workers in UV environments to advise workers of the risks of increased UV exposures that might be obtained from being in the proximity of highly UV reflective surfaces. A number of advisory documents make recommendations to workers who are regularly exposed to UV radiation, but most do not indicate the influence of reflective surfaces on potential UV exposures that can be incurred. It is recommended that these documents be updated, and the public and outdoor workers advised of the risks of UV radiation reflection through appropriate publications of the presented data.

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7 Appendices

7.1 Preliminary measurements of different surface types spectral reflection

7.1.1 Zinc aluminium corrugated

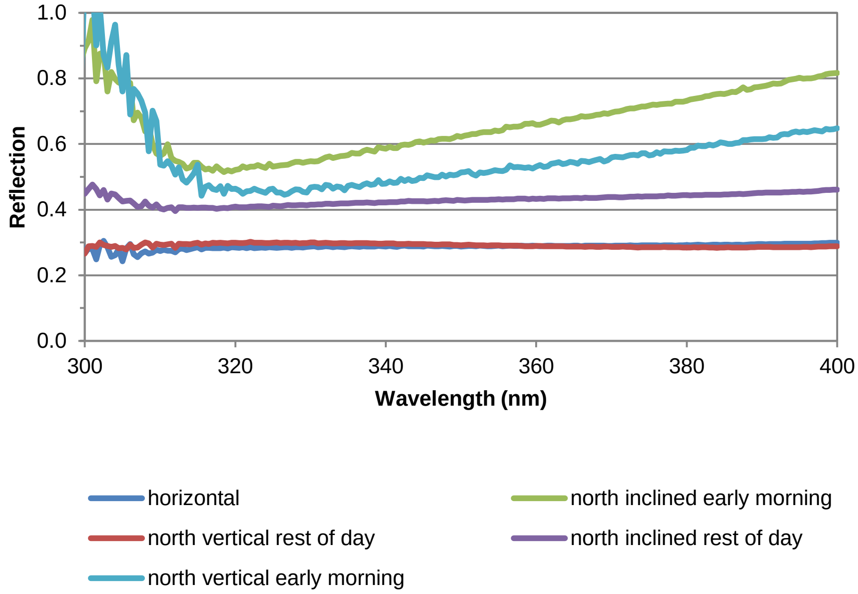


Figure 7.1 – Average reflection per wavelength from horizontal and north facing vertical and inclined surfaces at different SZA and SAA.

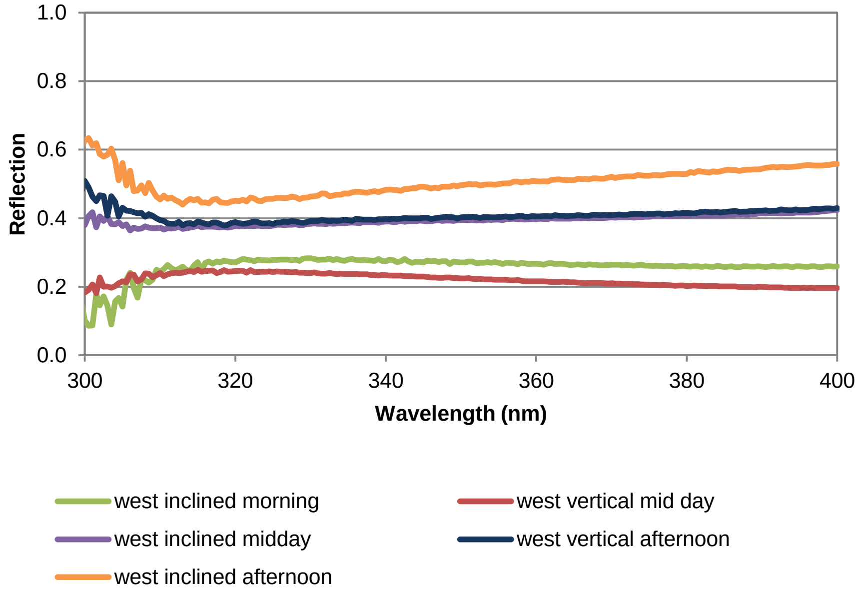


Figure 7.2 - Average reflection per wavelength from west facing vertical and inclined surfaces at different SZA and SAA.

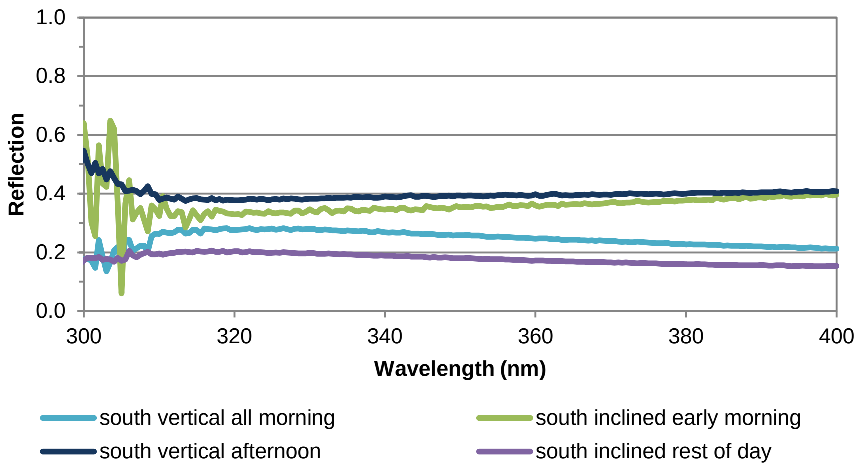


Figure 7.3 - Average reflection per wavelength for south facing vertical and inclined surfaces for varying SZA and SAA.

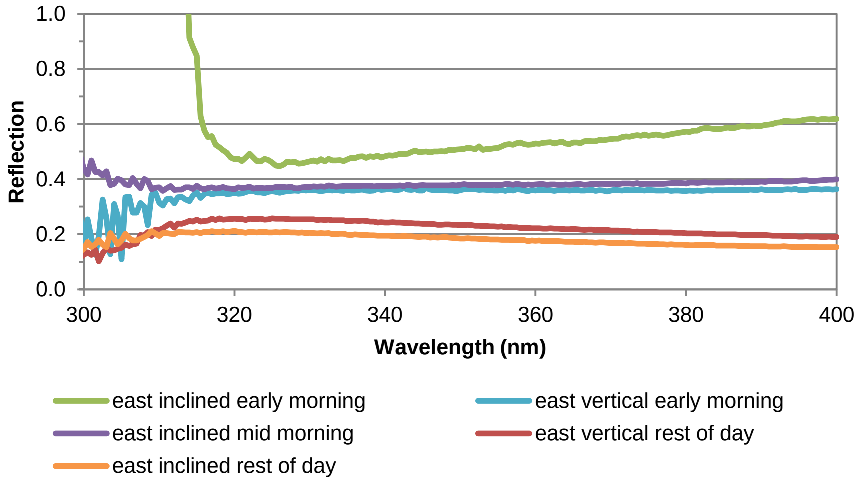


Figure 7.4 - Average reflection per wavelength for east facing vertical and inclined surfaces for varying SZA and SAA.

7.1.2 Beige trapezoidal

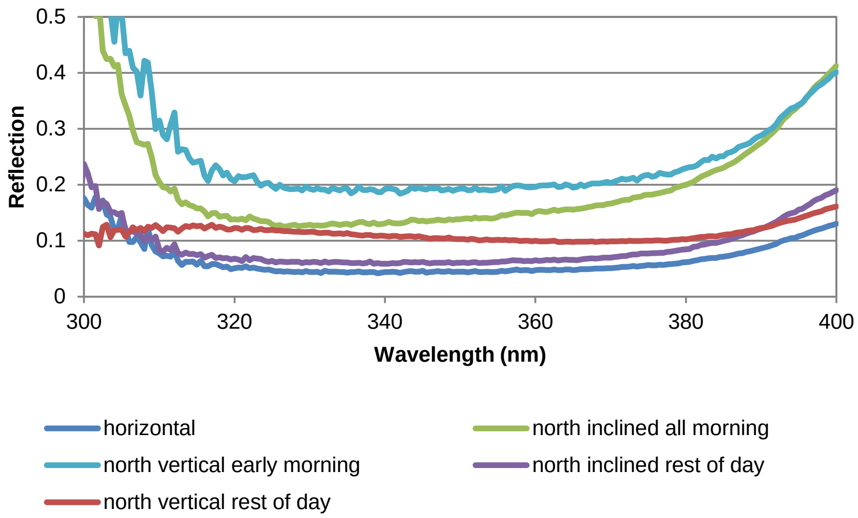


Figure 7.5 - Average reflection per wavelength for beige trapezoidal horizontal and north facing vertical and inclined surfaces at various SZA and SAA.

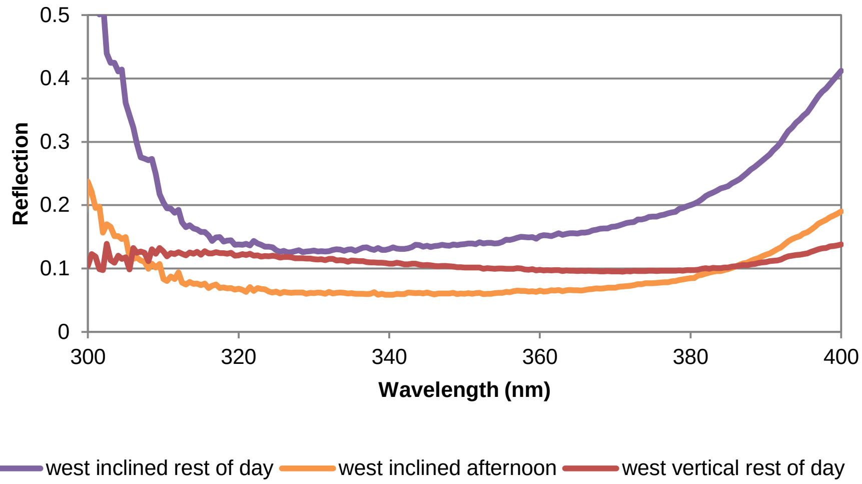


Figure 7.6 - Average reflection per wavelength for beige trapezoidal west facing vertical and inclined surface for varying SZA and SAA.

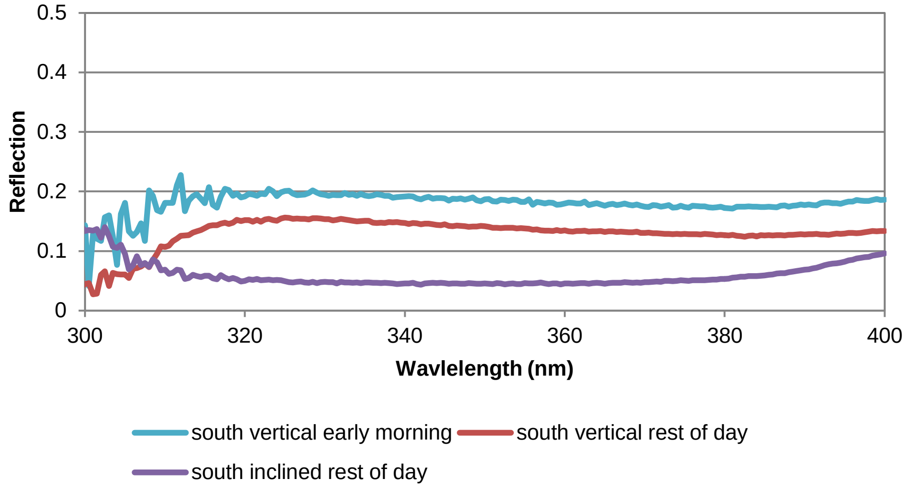


Figure 7.7 - Average reflection per wavelength for beige trapezoidal south facing vertical and inclined surface for varying SZA and SAA.

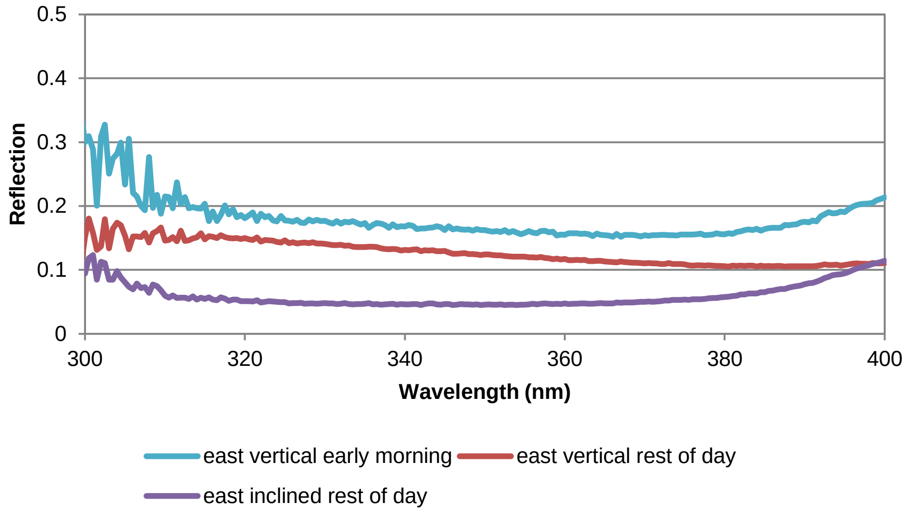


Figure 7.8 - Average reflection per wavelength for beige trapezoidal east vertical and inclined surfaces for varying SZA and SAA.

7.1.3 Cream trapezoidal

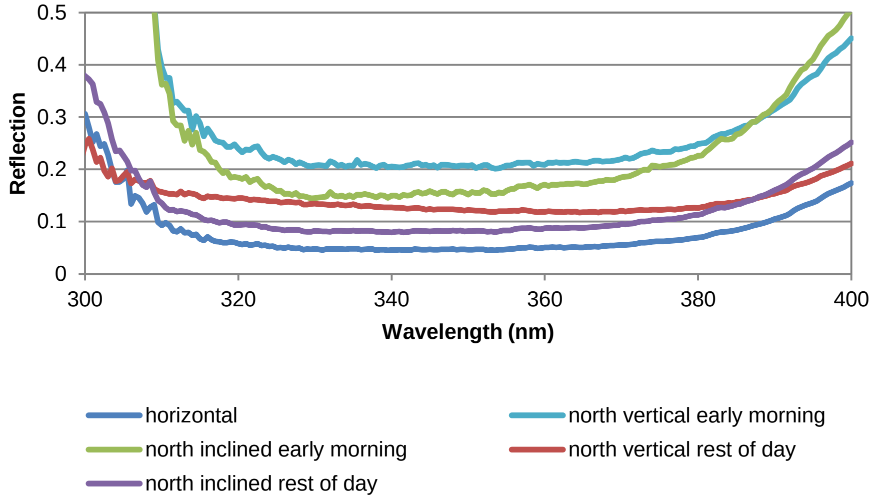


Figure 7.9 - Average reflection per wavelength for cream trapezoidal horizontal and north facing vertical and inclined surfaces for varying SZA and SAA.

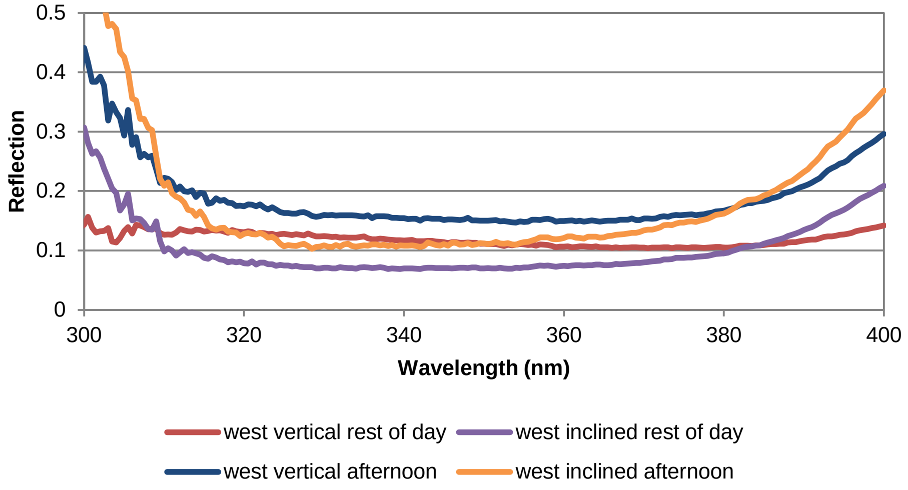


Figure 7.10 - Average reflection per wavelength for cream trapezoidal west facing vertical and inclined surfaces for varying SZA and SAA.

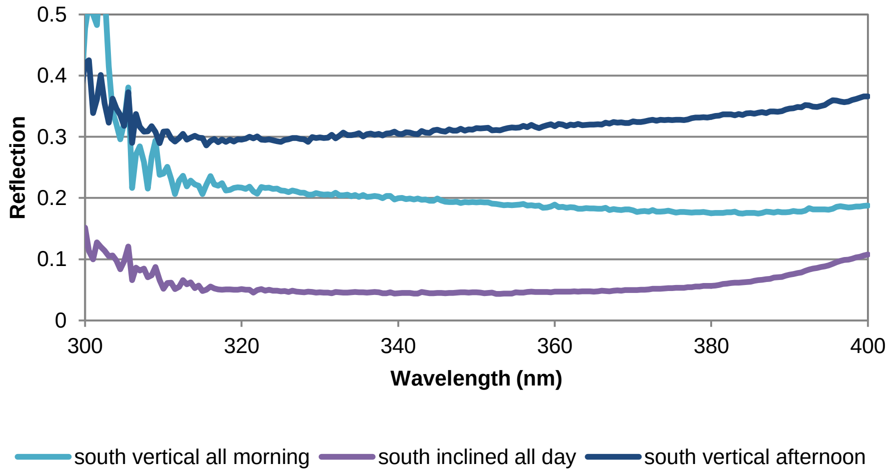


Figure 7.11 - Average reflection per wavelength for cream trapezoidal south facing vertical and inclined surfaces for varying SZA and SAA.

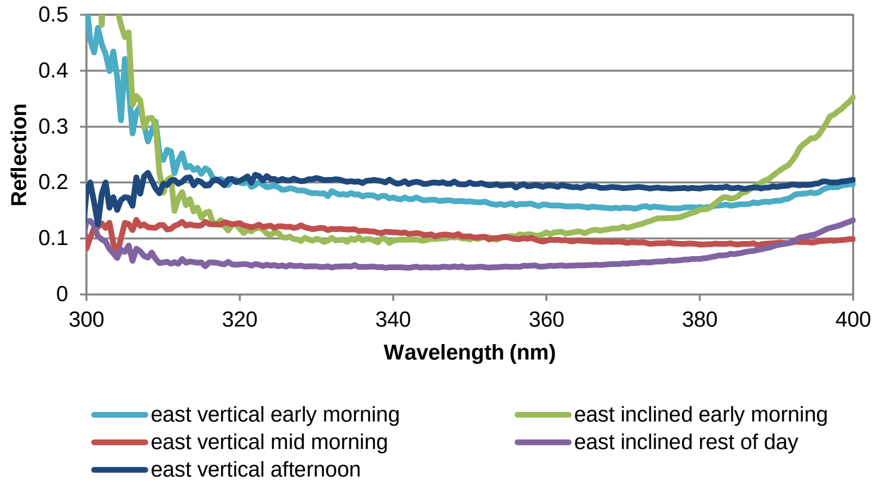


Figure 7.12 - Average reflection per wavelength for cream trapezoidal east facing vertical and inclined surfaces for varying SZA and SAA.

7.1.4 Cream corrugated

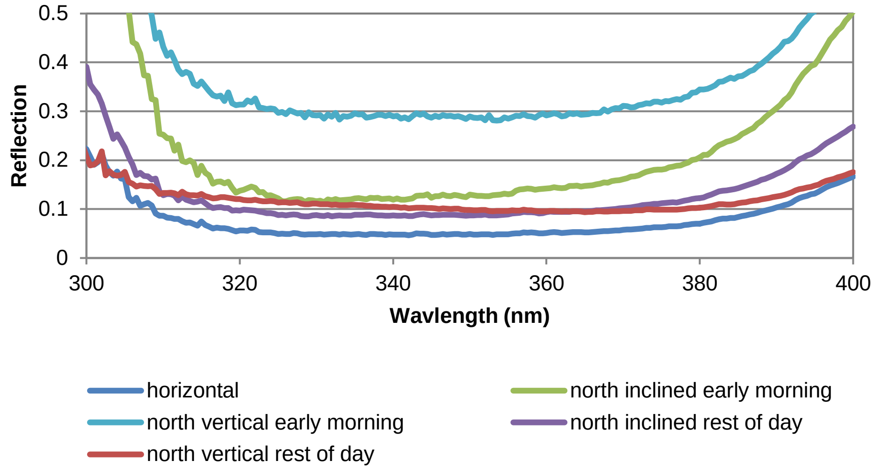


Figure 7.13 - Average reflection per wavelength for cream corrugated horizontal, north facing vertical and inclined surfaces with varying SZA and SAA.

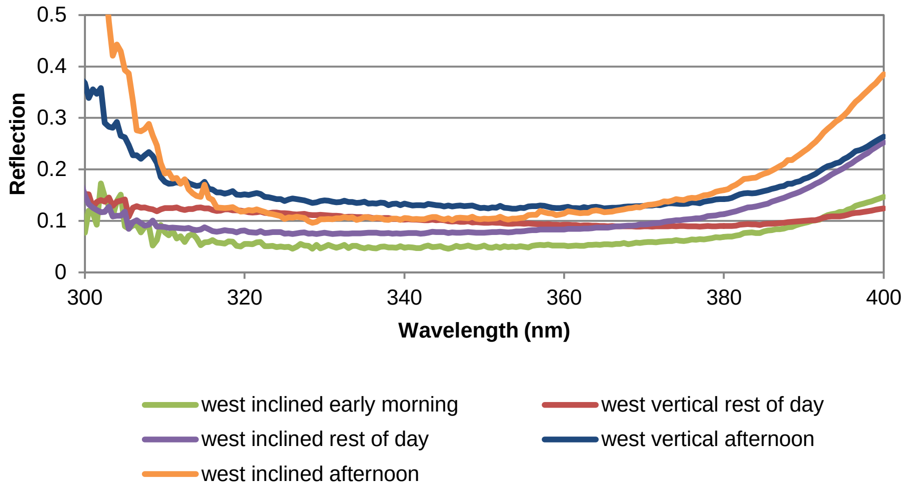


Figure 7.14 - Average reflection per wavelength for cream corrugated west facing vertical and inclined facing surfaces with varying SZA and SAA.

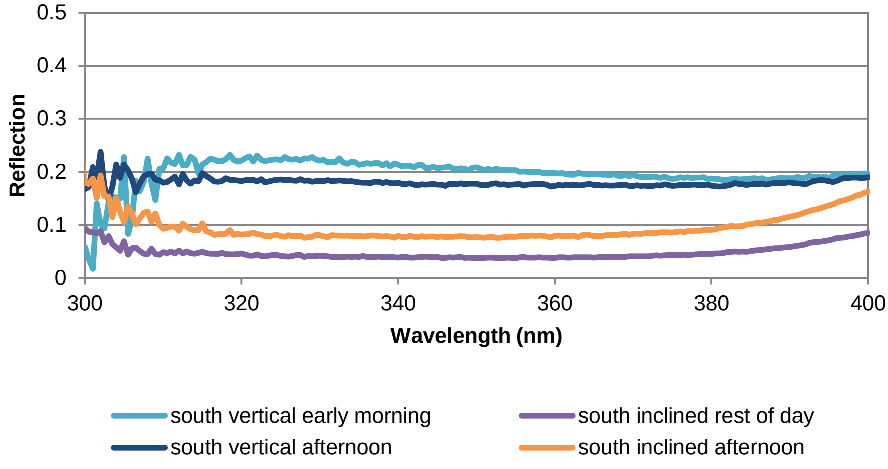


Figure 7.15 - Average reflection per wavelength for cream corrugated south vertical or inclined facing surfaces for varying SZA and SAA.

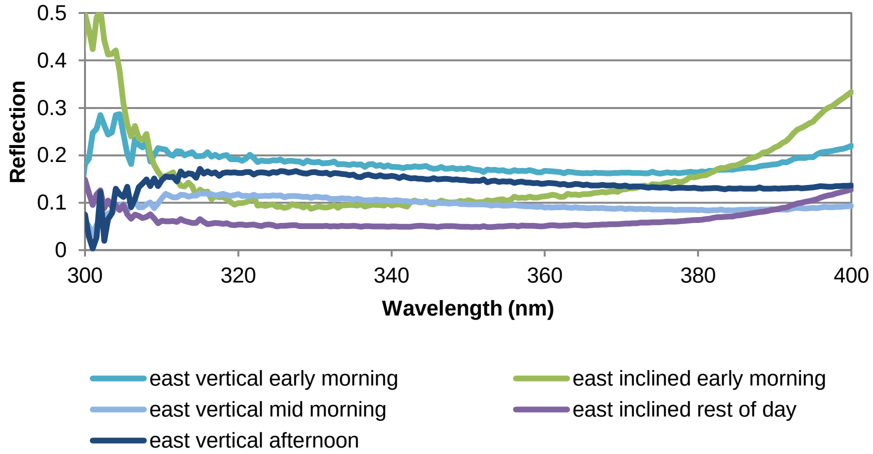


Figure 7.16 - Average reflection per wavelength for cream corrugated east vertical and inclined facing surfaces for varying SZA and SAA.

7.1.5 Medium blue trapezoidal

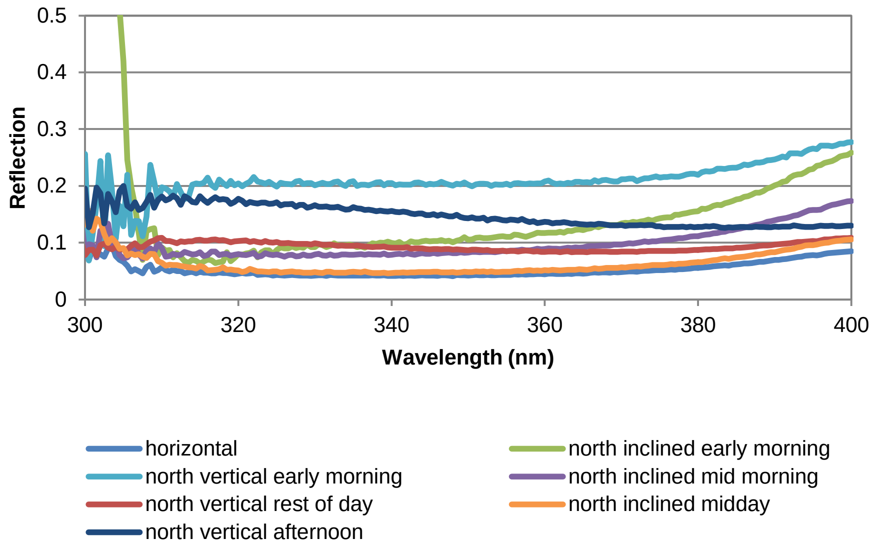


Figure 7.17 - Average reflection per wavelength for medium blue trapezoidal for horizontal, and north facing vertical and inclined surfaces for varying SZA and SAA.

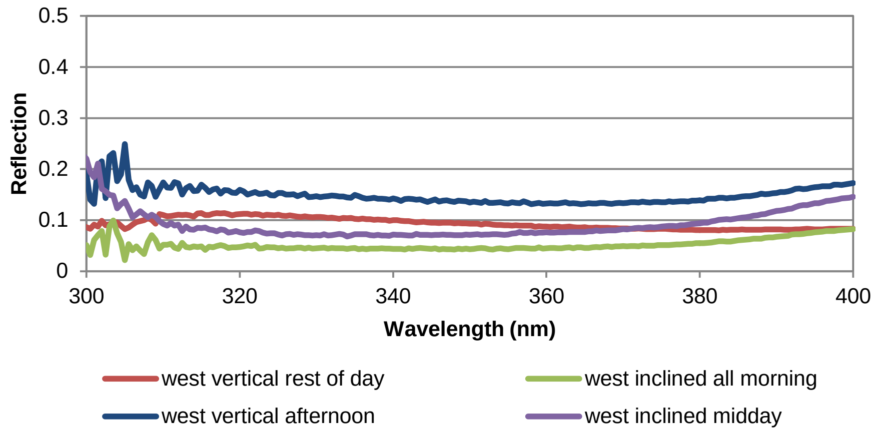


Figure 7.18 - Average reflection per wavelength for medium blue trapezoidal west facing vertical and inclined surfaces for varying SZA and SAA.

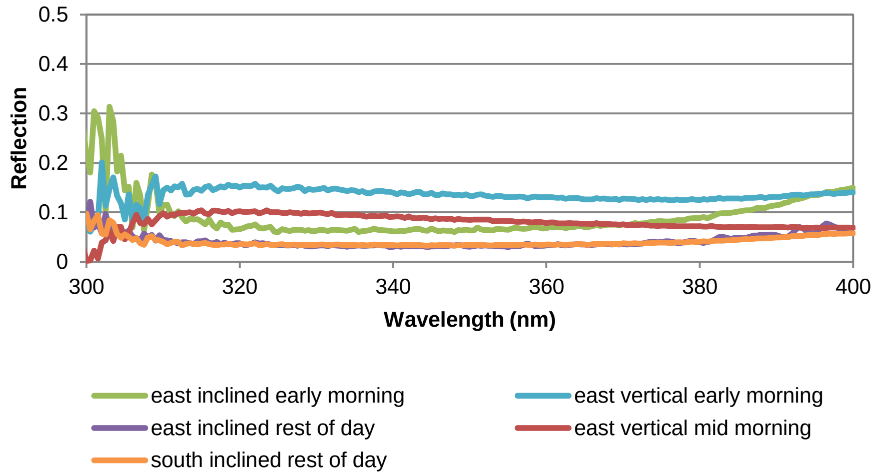


Figure 7.19 - Average reflection per wavelength for south inclined or east facing vertical and inclined surfaces for varying SZA and SAA.

7.1.6 Insultec coated (zinc aluminium) trapezoidal

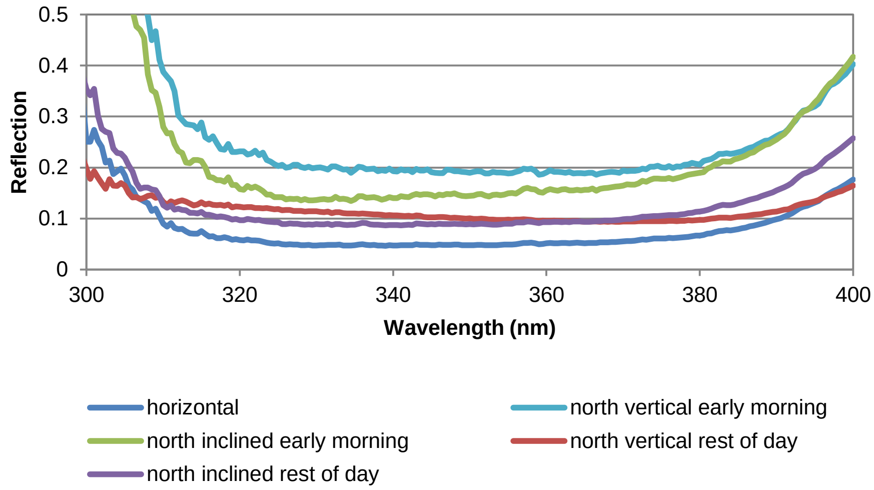


Figure 7.20 - Average reflection per wavelength for Insultec coated trapezoidal for horizontal and north vertical and inclined surfaces for varying SZA and SAA.

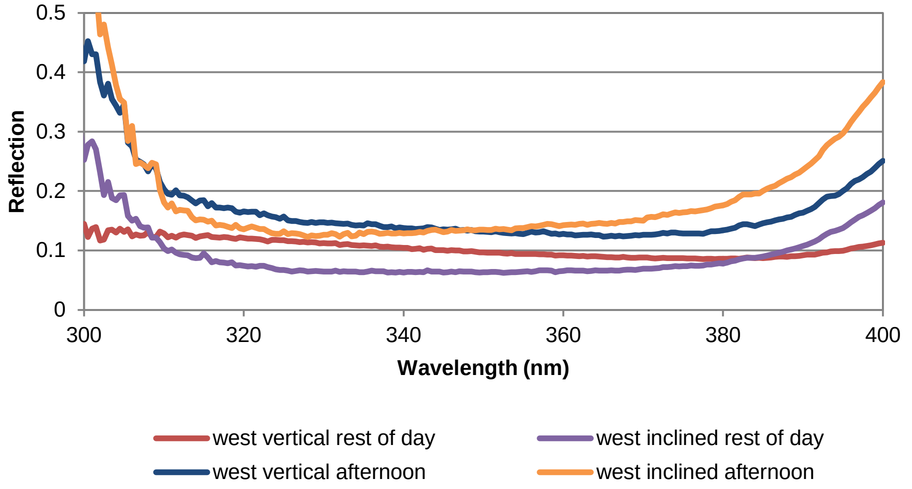


Figure 7.21 - Average reflection per wavelength for Insultec coated trapezoidal for west facing vertical and inclined surfaces for varying SZA and SAA.

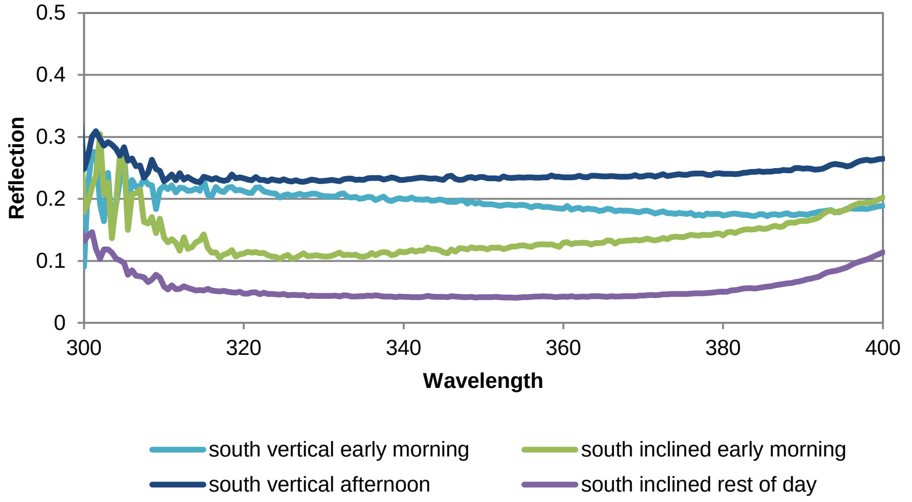


Figure 7.22 - Average reflection per wavelength for insultec trapezoidal for south facing vertical and inclined surfaces for varying SZA and SAA.

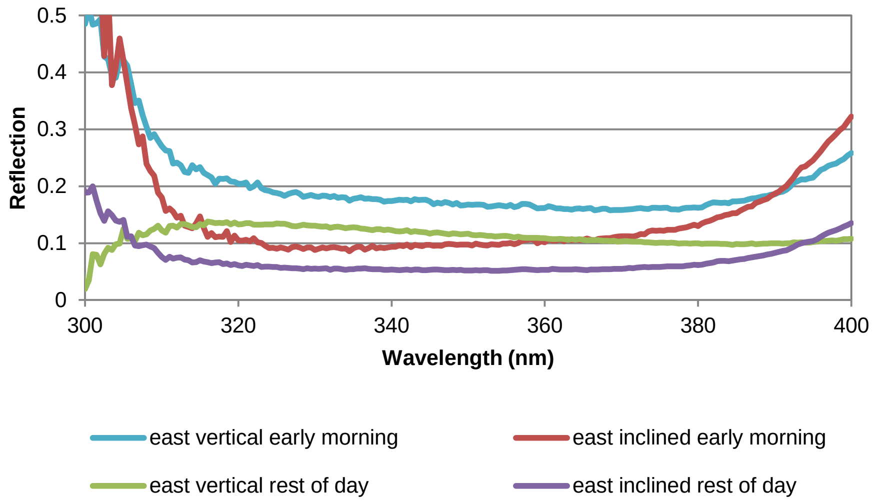


Figure 7.23 - Average reflection per wavelength for insultec coated trapezoidal for east facing vertical and inclined surfaces for varying SZA and SAA.

7.1.7 Black trapezoidal

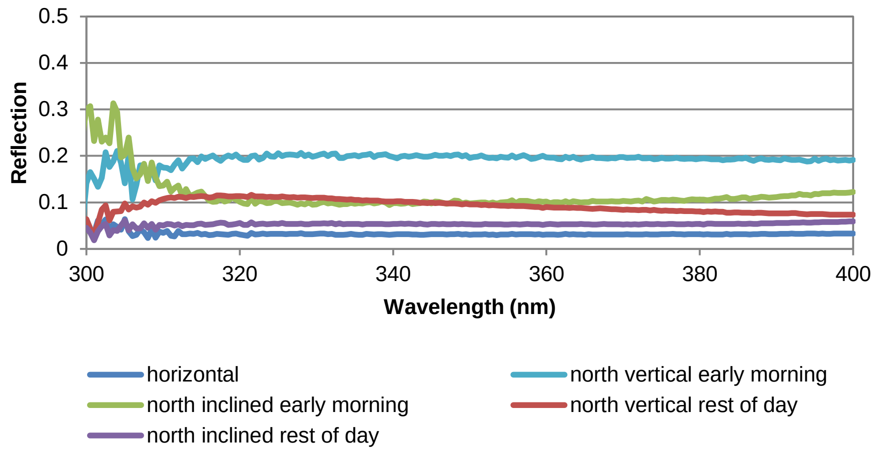


Figure 7.24 - Average reflection per wavelength for black trapezoidal for horizontal, north facing vertical and inclined surfaces for varying SZA and SAA.

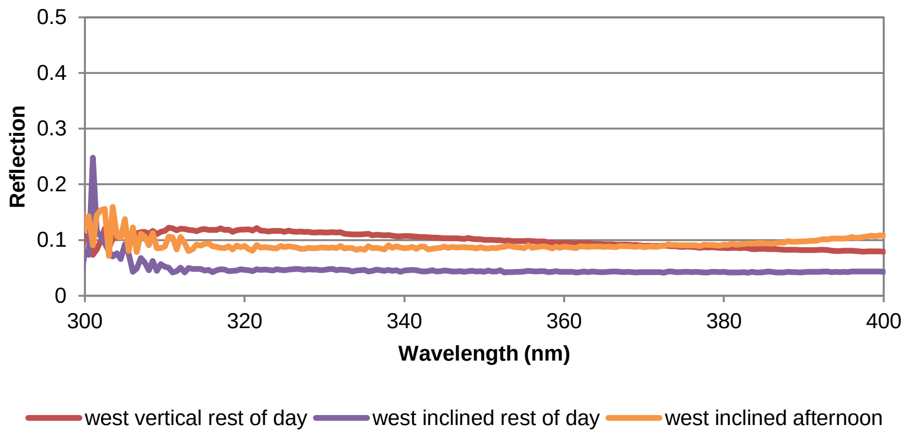


Figure 7.25 - Average reflection per wavelength for black trapezoidal for west facing vertical and inclined surfaces for varying SZA and SAA.

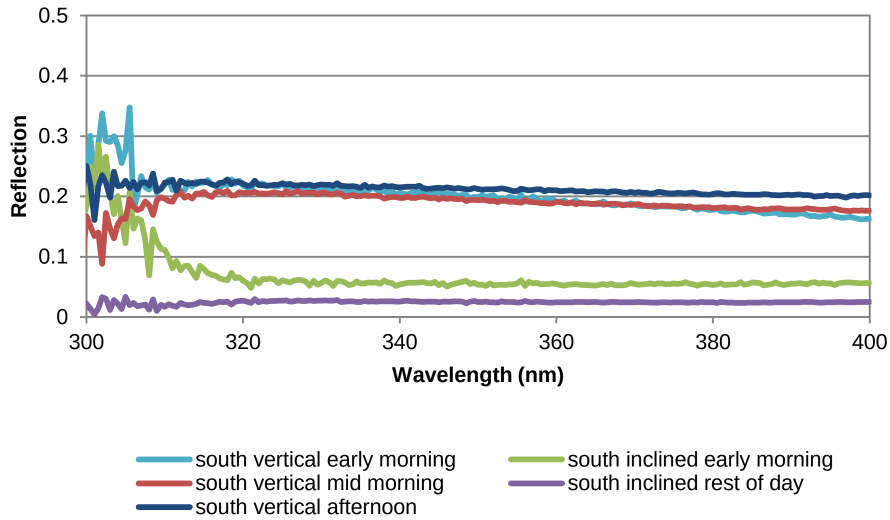


Figure 7.26 - Average reflection per wavelength for black trapezoidal for south facing vertical and inclined surfaces for varying SZA and SAA.

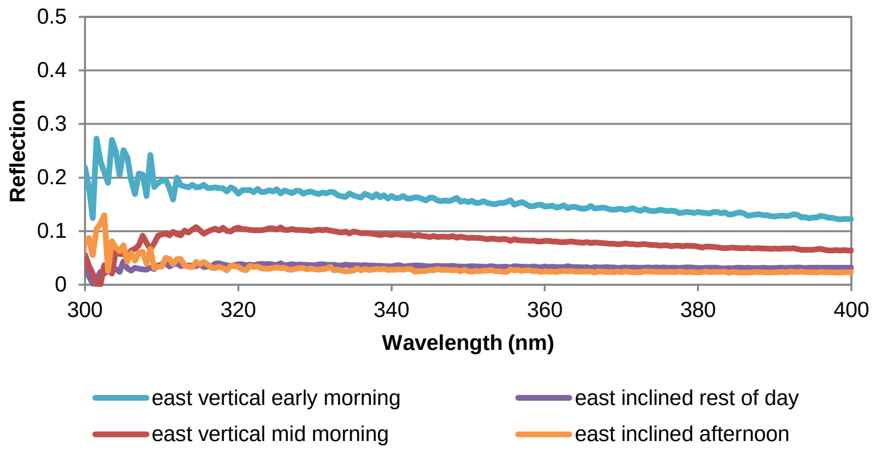


Figure 7.27 - Average reflection per wavelength for black trapezoidal for east facing vertical and inclined surfaces for varying SZA and SAA.

7.1.8 Dark red trapezoidal

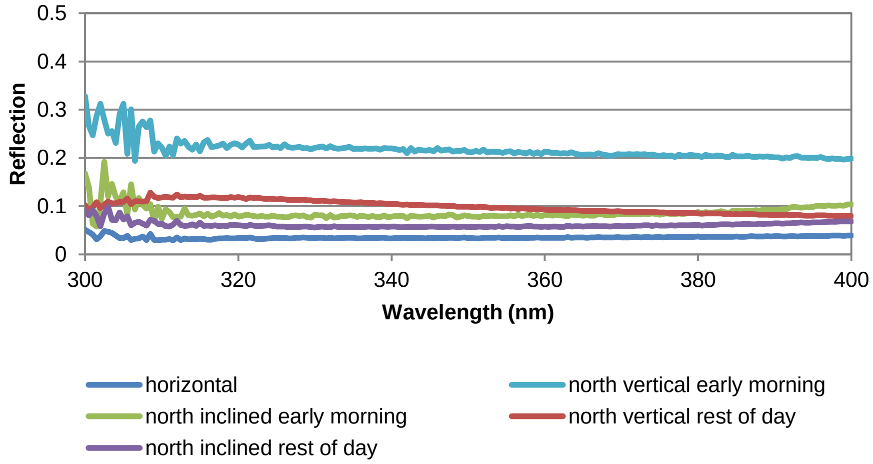


Figure 7.28 - Average reflection per wavelength for dark red trapezoidal for horizontal and north facing vertical and inclined surfaces for varying SZA and SAA.

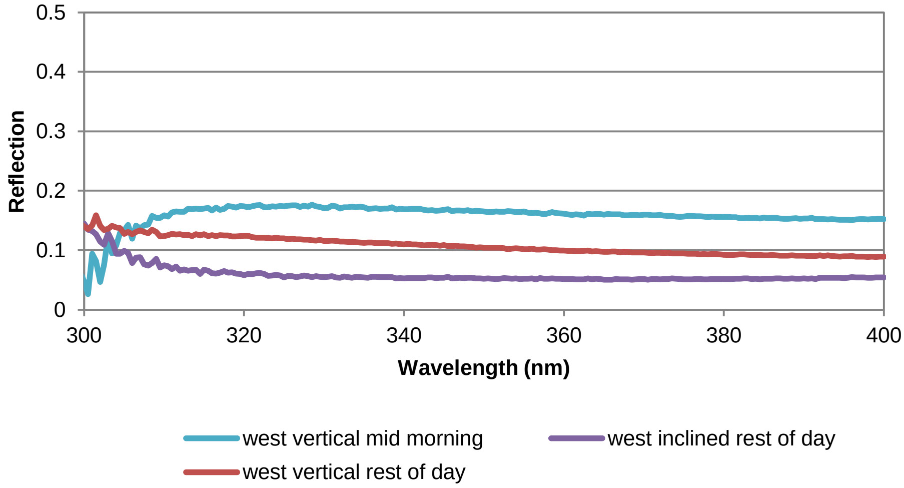


Figure 7.29 - Average reflection per wavelength for dark red trapezoidal for west facing vertical and inclined surfaces for varying SZA and SAA.

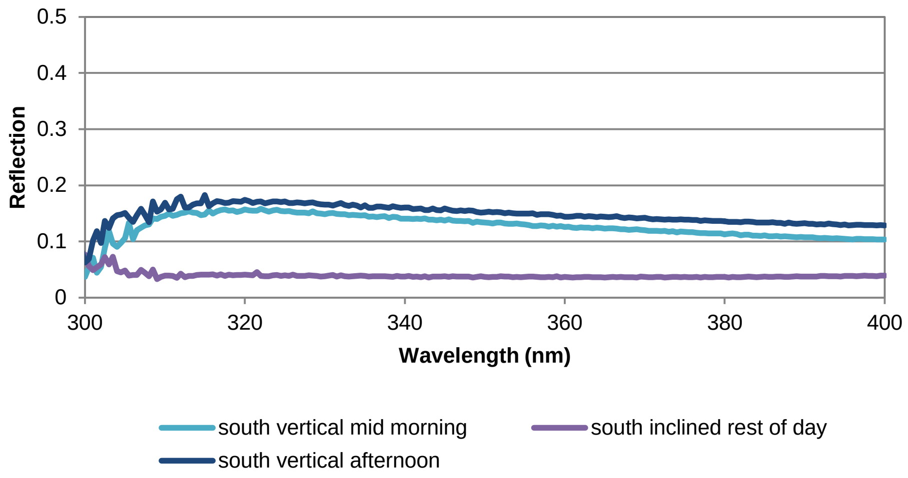


Figure 7.30 - Average reflection per wavelength for dark red trapezoidal for south facing vertical and inclined surfaces for varying SZA and SAA.

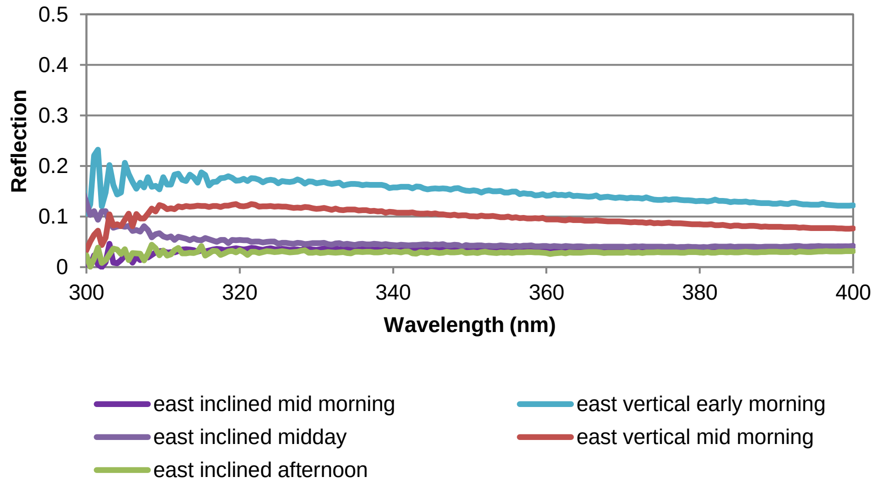


Figure 7.31 - Average reflection per wavelength for dark red trapezoidal for east facing vertical and inclined surfaces for varying SZA and SAA.

7.1.9 Pale green trapezoidal

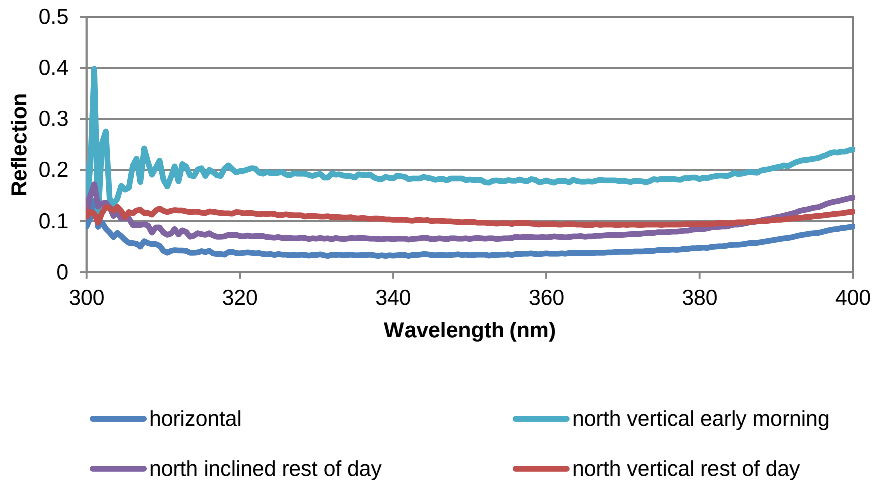


Figure 7.32 - Average reflection per wavelength for pale green trapezoidal for horizontal and north facing vertical and inclined surfaces for varying SZA and SAA.

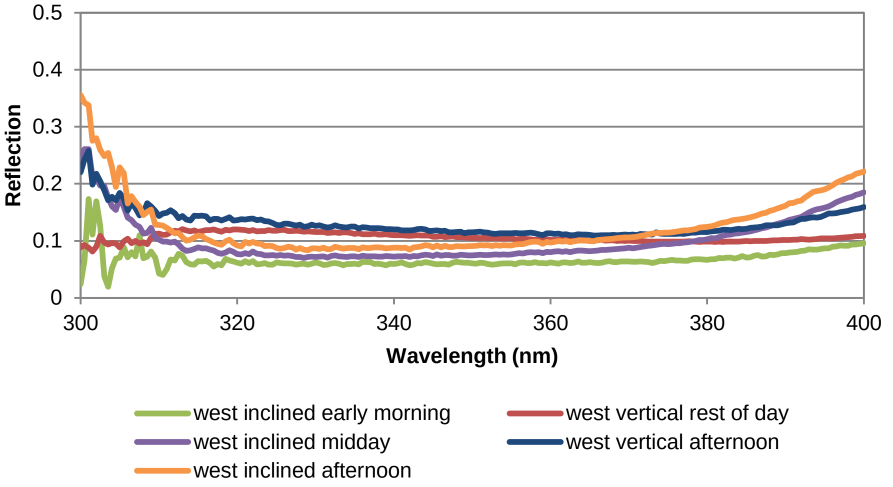


Figure 7.33 - Average reflection per wavelength for pale green trapezoidal for west facing vertical and inclined surfaces for varying SZA and SAA.

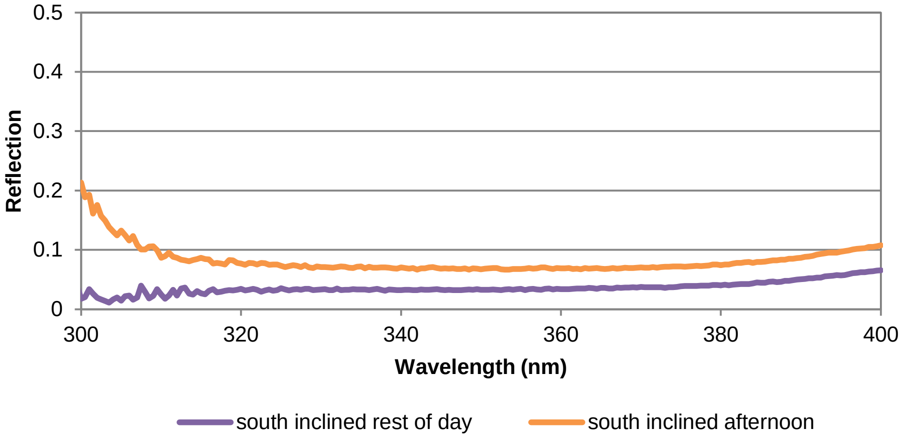


Figure 7.34 - Average reflection per wavelength for pale green trapezoidal south facing inclined surfaces for varying SZA and SAA.

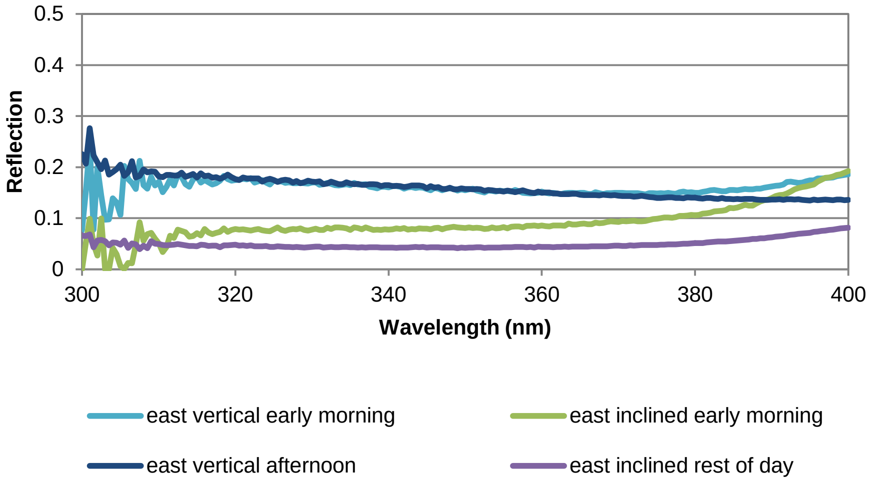


Figure 7.35 - Average reflection per wavelength for pale green trapezoidal east facing vertical and inclined surfaces for varying SZA and SAA.

7.2 Remaining surface types – repeated measurements

7.2.1 Insultec coated trapezoidal

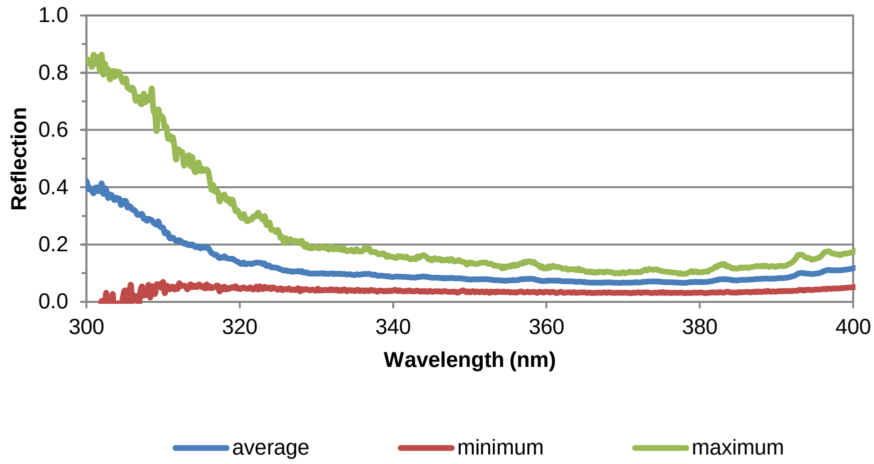


Figure 7.36 - Average, minimum and maximum reflection from an Insultec trapezoidal vertical surface during Winter and Spring 2010.

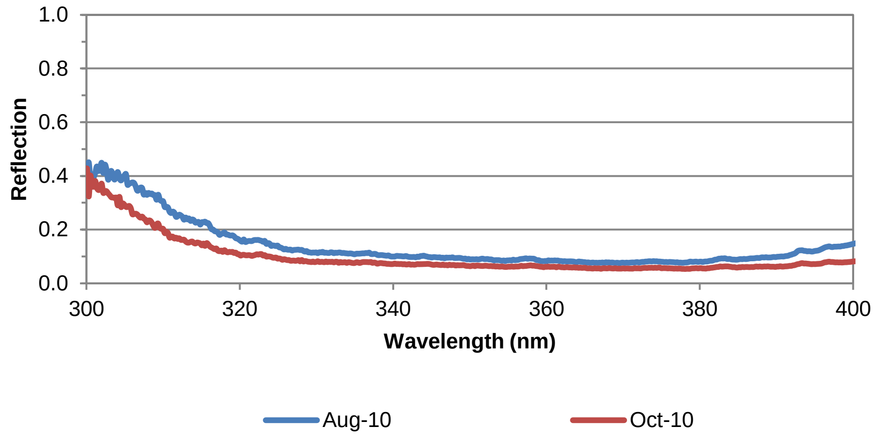
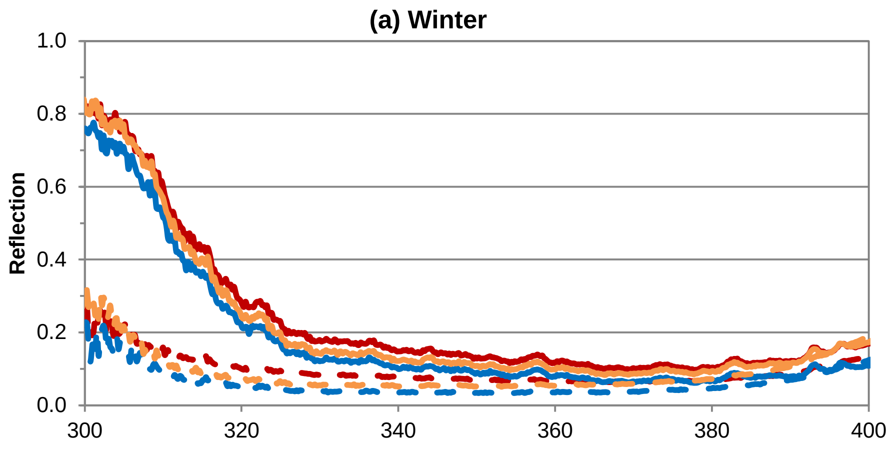


Figure 7.37 - Average daily reflection from Insultec trapezoidal vertical north facing surface for all measurement sessions.



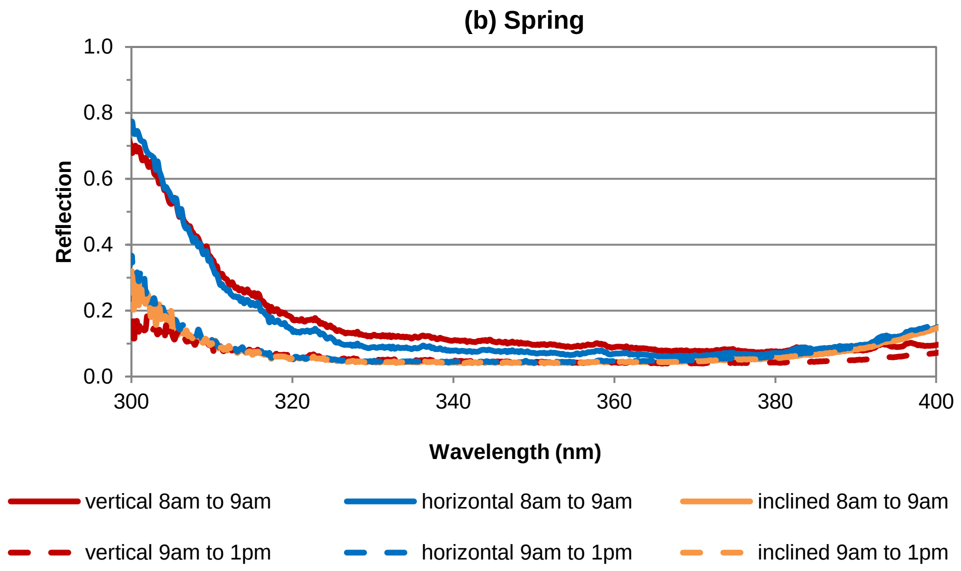


Figure 7.38 - Average reflection for Insultec trapezoidal for horizontal and north facing vertical and inclined surfaces for varying SZA and SAA in (a)Winter 2010 and (b) Spring 2010.

7.2.2 Beige trapezoidal

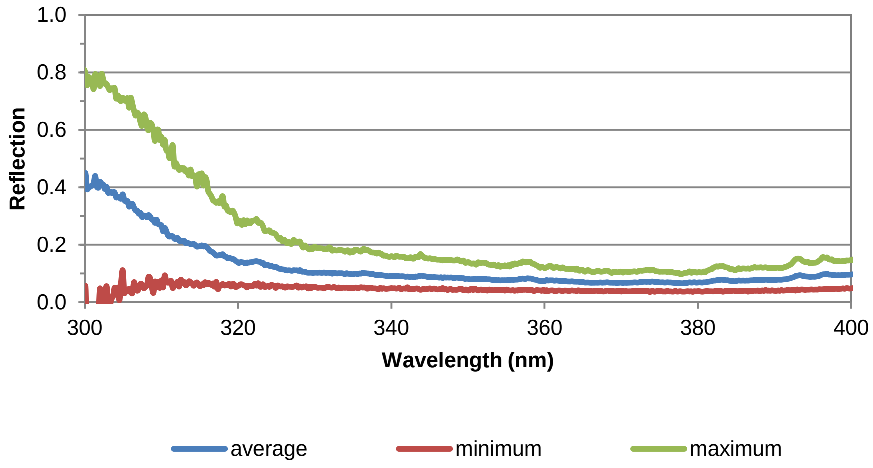


Figure 7.39 - Average, minimum and maximum reflection from a beige trapezoidal vertical surface during Winter and Spring 2010.

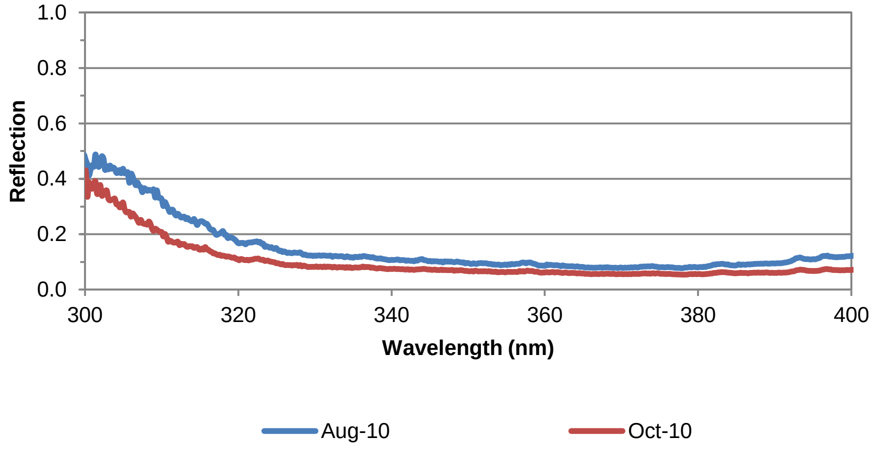


Figure 7.40 - Average daily reflection from beige trapezoidal vertical north facing surface for all measurement sessions.

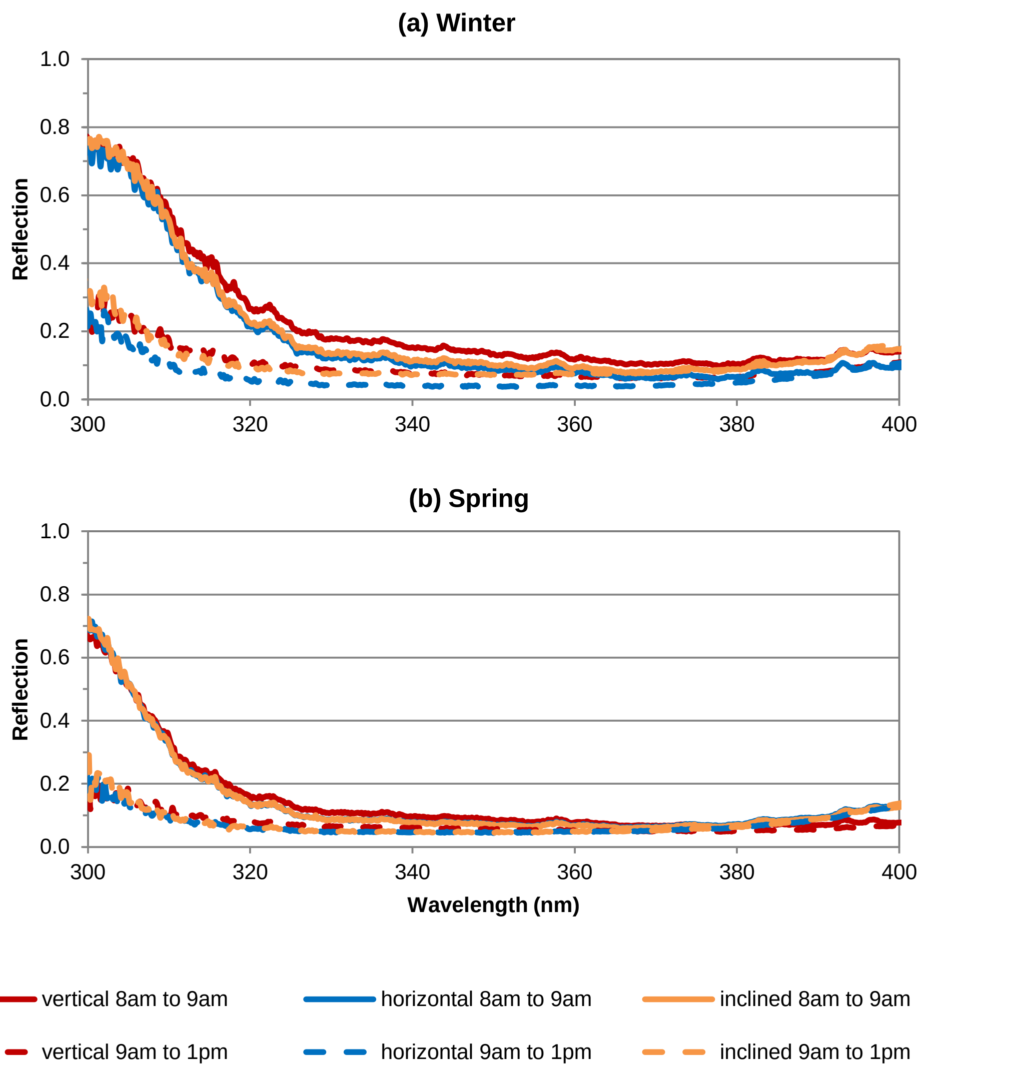


Figure 7.41 - Average reflection for beige trapezoidal for horizontal and north facing vertical and inclined surfaces for varying SZA and SAA in (a)Winter 2010 and (b) Spring 2010.

7.2.3 Dark green trapezoidal

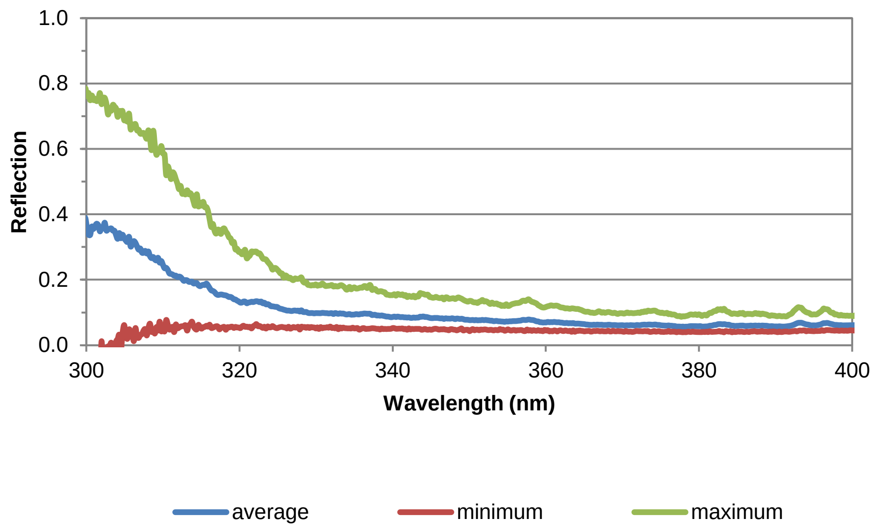


Figure 7.42 - Average, minimum and maximum reflection from a dark green trapezoidal vertical surface during Winter and Spring 2010.

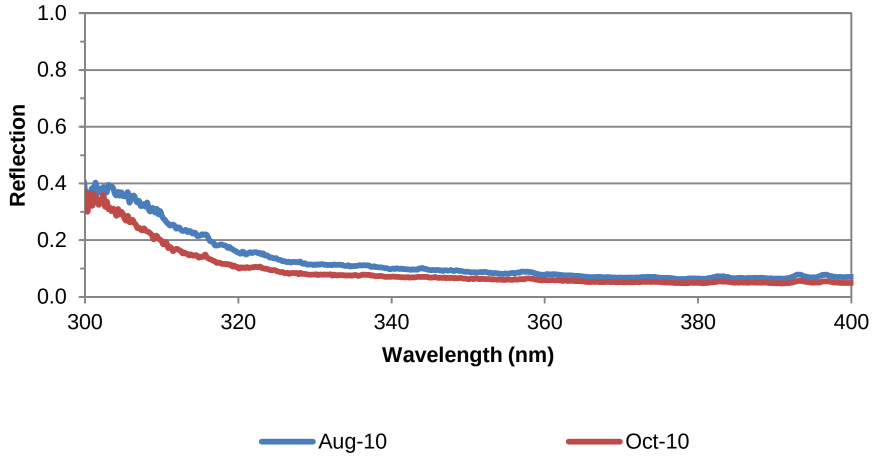


Figure 7.43 - Average daily reflection from dark green trapezoidal vertical north facing surface for all measurement sessions.

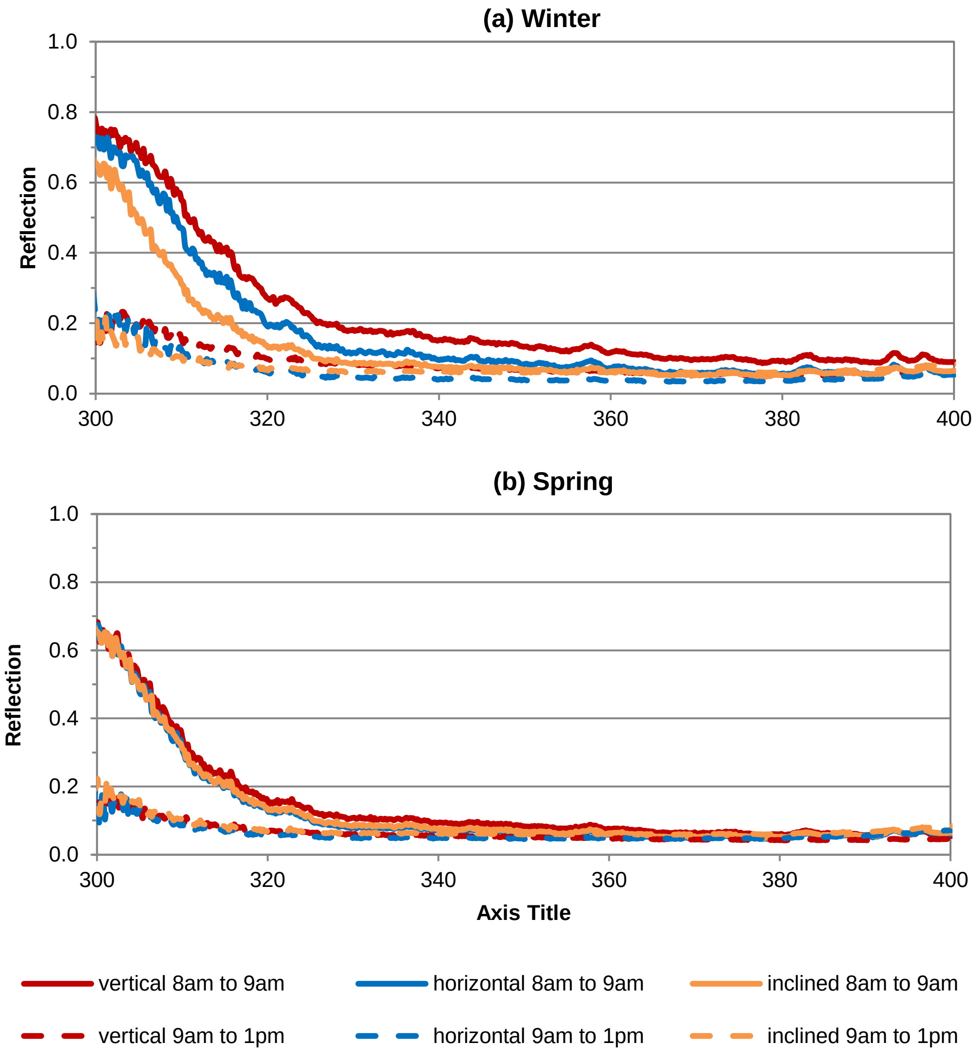


Figure 7.44 - Average reflection for dark green trapezoidal for horizontal and north facing vertical and inclined surfaces for varying SZA and SAA in (a)Winter 2010 and (b) Spring 2010.

7.2.4 Dark green corrugated

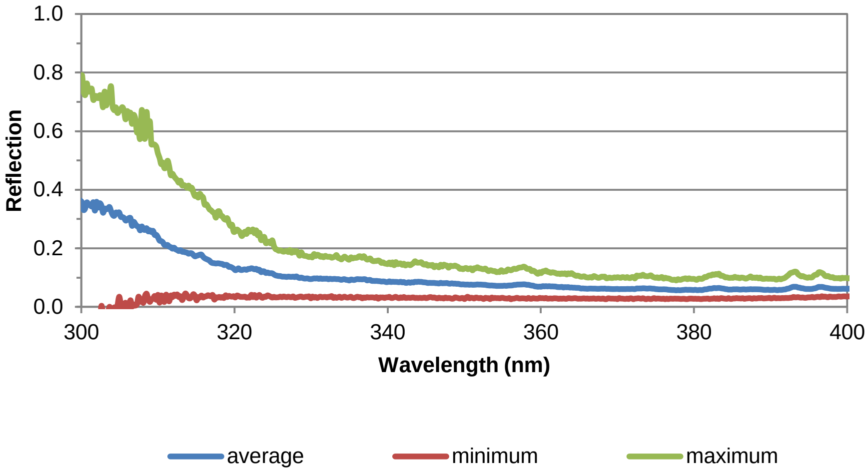


Figure 7.45 - Average, minimum and maximum reflection from a dark green corrugated vertical surface during Winter and Spring 2010.

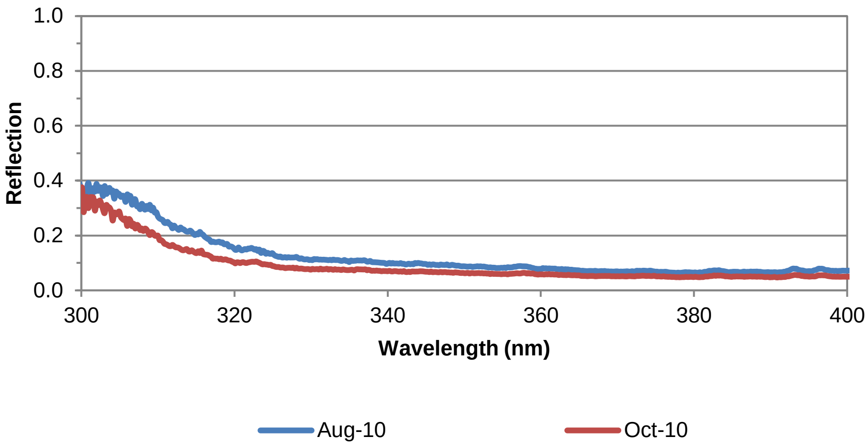
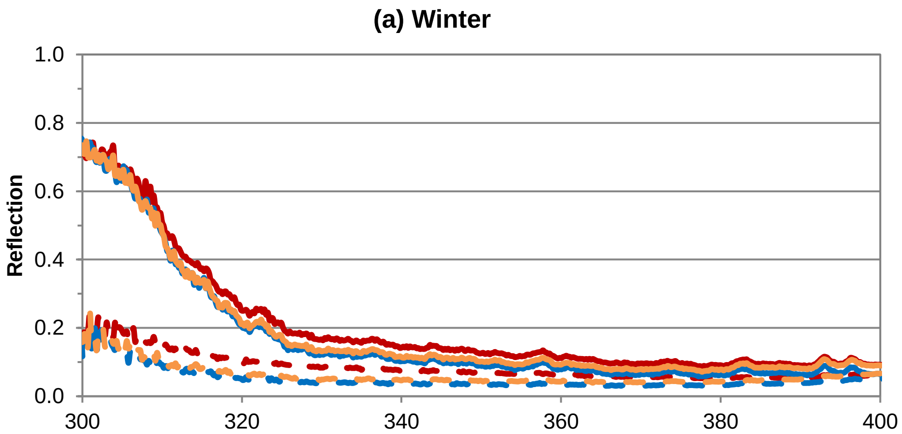


Figure 7.46 - Average daily reflection from dark green corrugated vertical north facing surface for all measurement sessions.



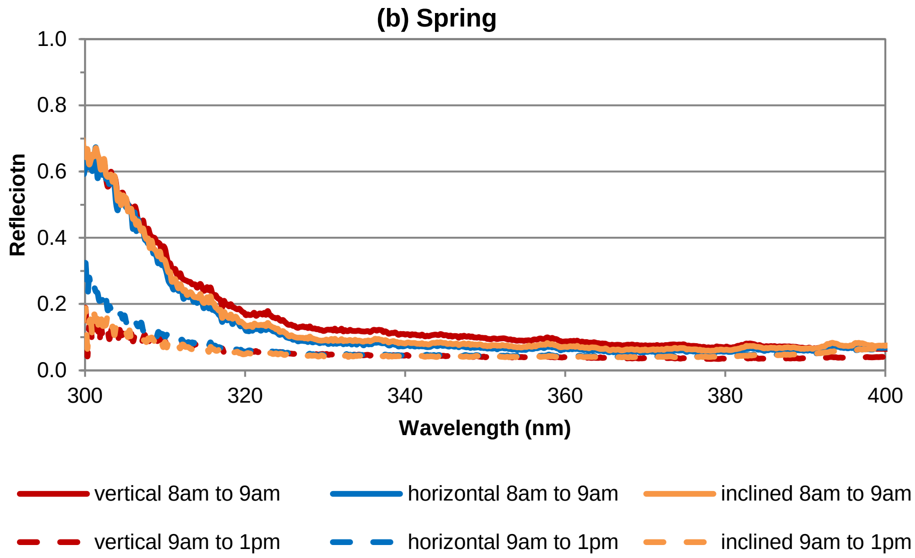


Figure 7.47 - Average reflection for dark green corrugated for horizontal and north facing vertical and inclined surfaces for varying SZA and SAA in (a)Winter 2010 and (b) Spring 2010.

7.2.5 Black trapezoidal

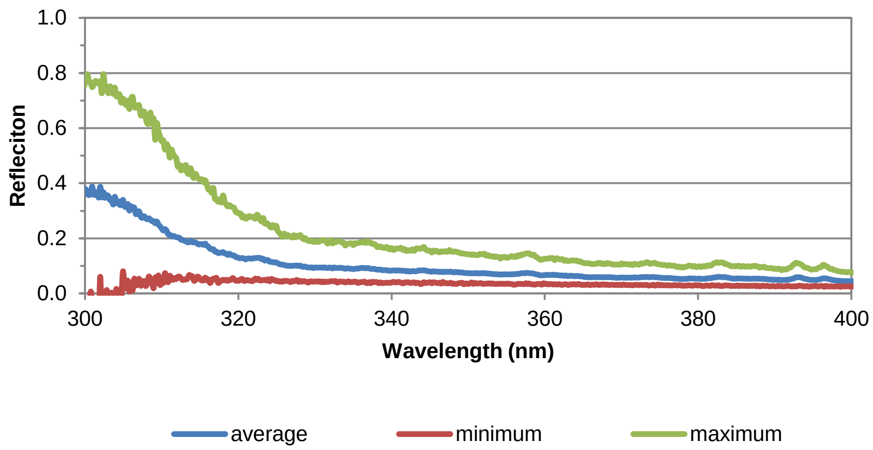


Figure 7.48 - Average, minimum and maximum reflection from a black trapezoidal vertical surface during Winter and Spring 2010.

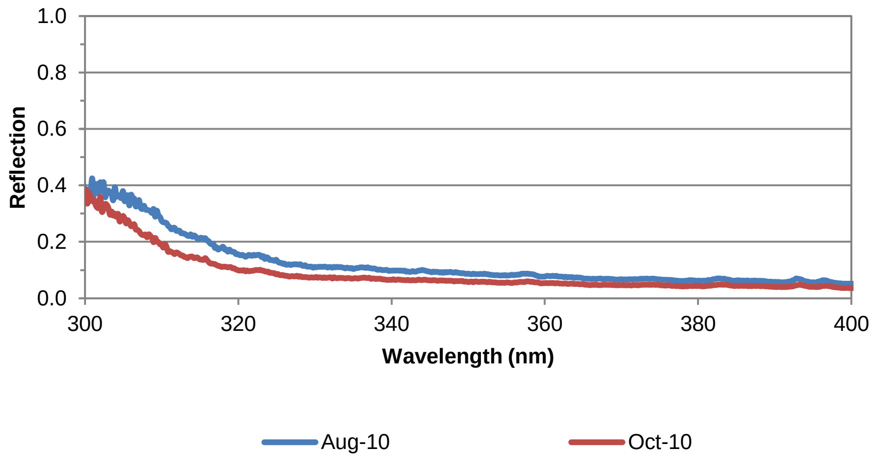


Figure 7.49 - Average daily reflection from black trapezoidal vertical north facing surface for all measurement sessions.

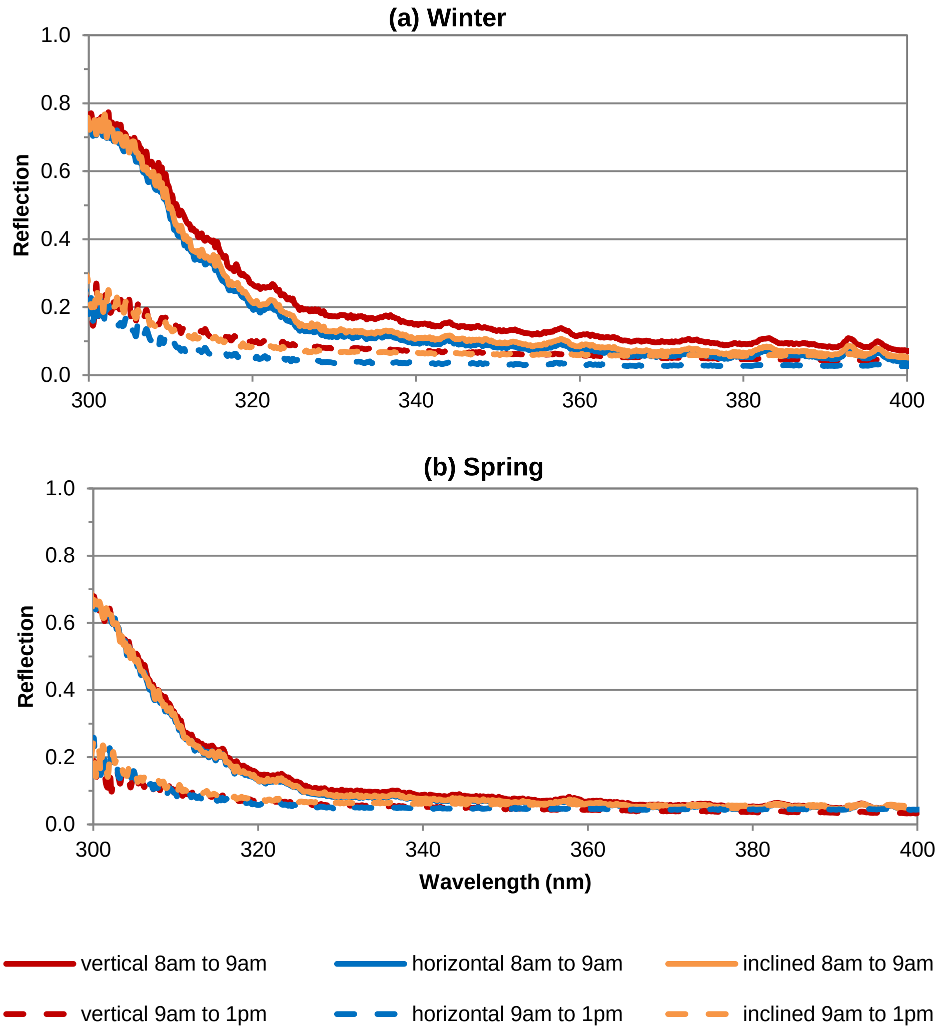


Figure 7.50 - Average reflection for black trapezoidal for horizontal and north facing vertical and inclined surfaces for varying SZA and SAA in (a)Winter 2010 and (b) Spring 2010.

7.2.6 Dark red trapezoidal

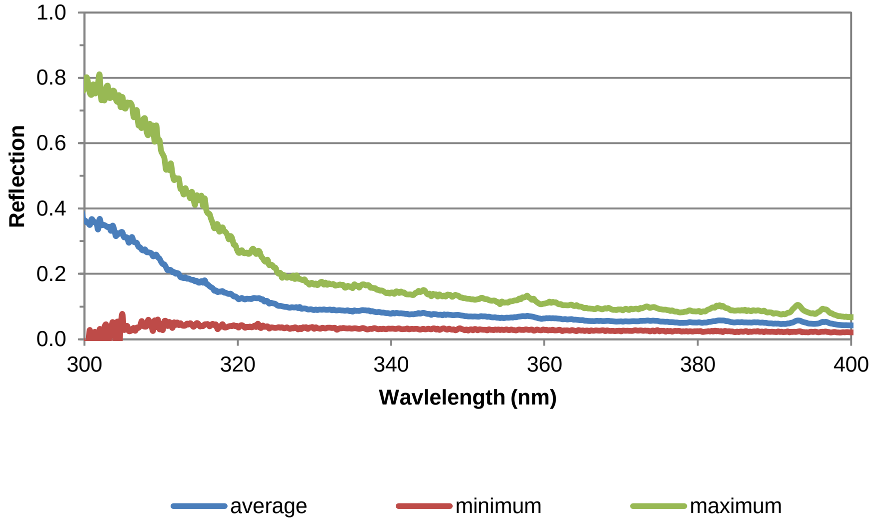


Figure 7.51 - Average, minimum and maximum reflection from a dark red trapezoidal vertical surface during Winter and Spring 2010.

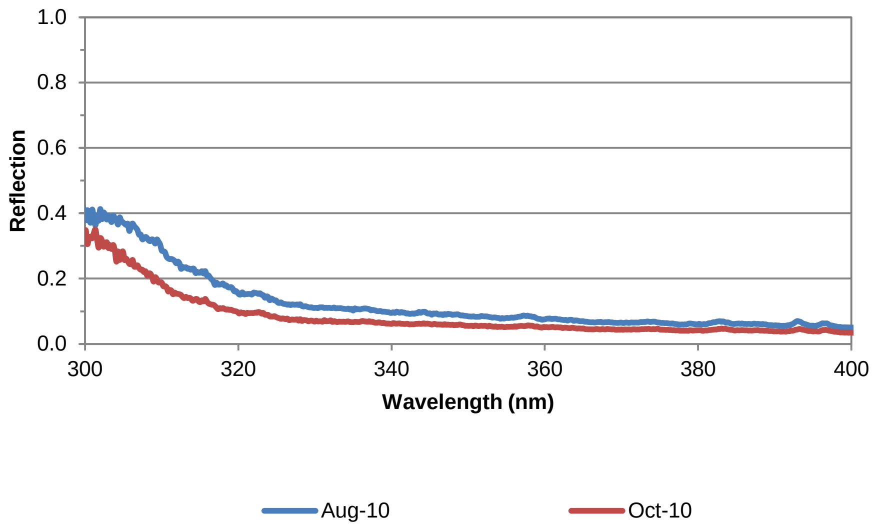


Figure 7.52 - Average daily reflection from dark red trapezoidal vertical north facing surface for all measurement sessions.

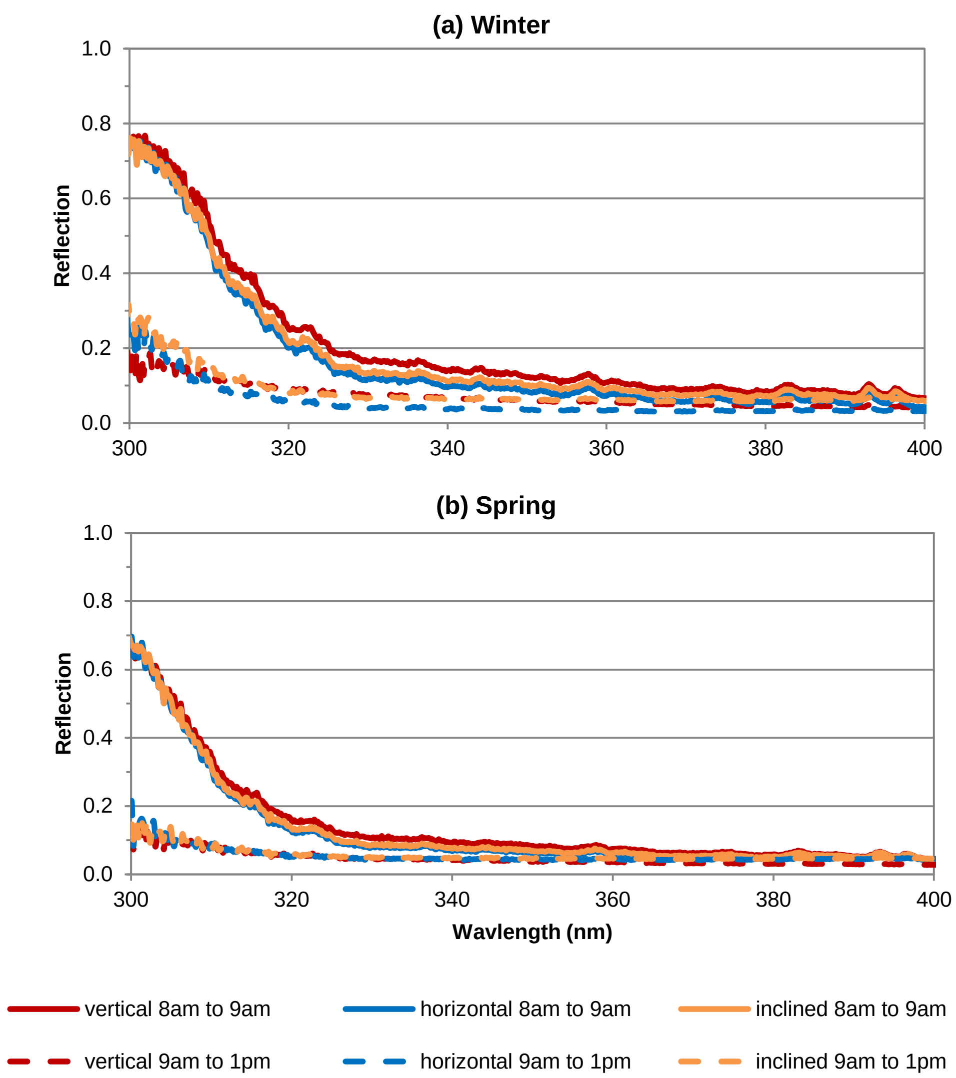


Figure 7.53 - Average reflection for dark red trapezoidal for horizontal and north facing vertical and inclined surfaces for varying SZA and SAA in (a)Winter 2010 and (b) Spring 2010.

7.2.7 Medium blue trapezoidal

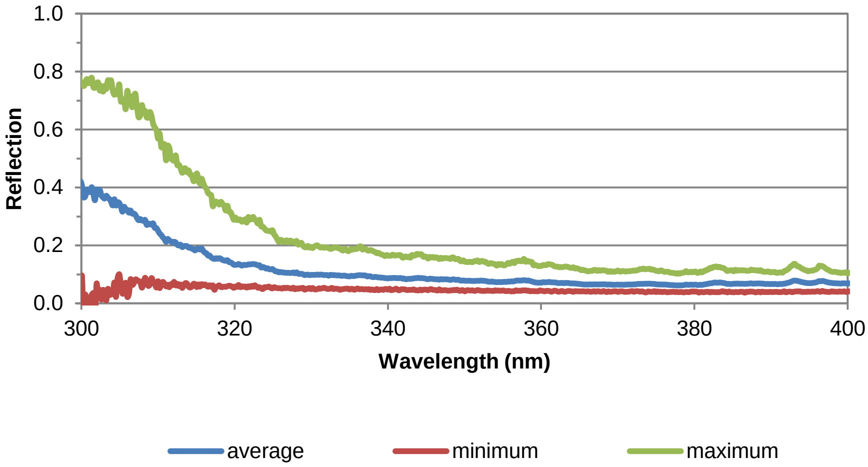


Figure 7.54 - Average, minimum and maximum reflection from a medium blue trapezoidal vertical surface during Winter and Spring 2010.

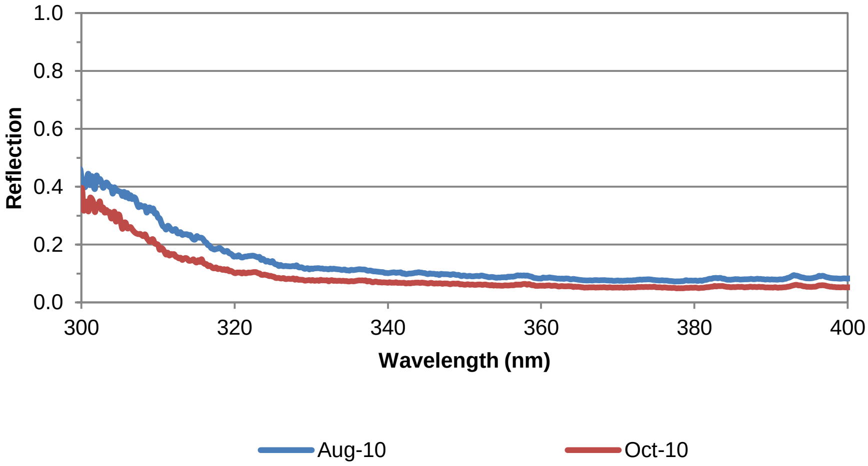
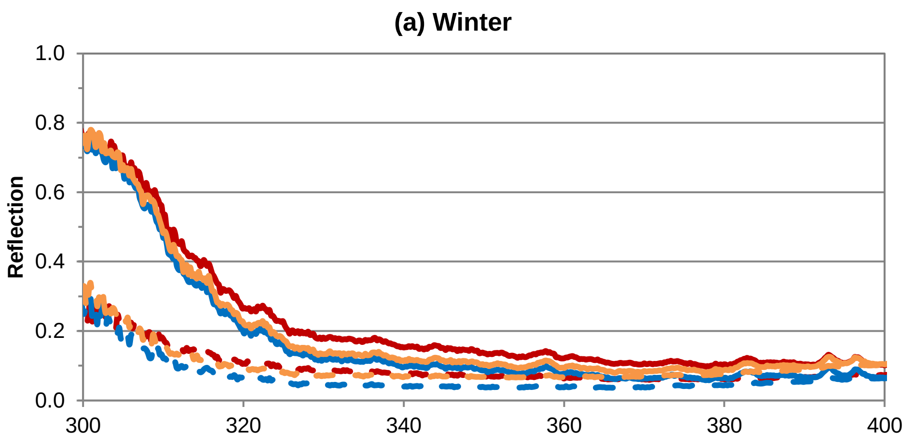


Figure 7.55 - Average daily reflection from medium blue trapezoidal vertical north facing surface for all measurement sessions.



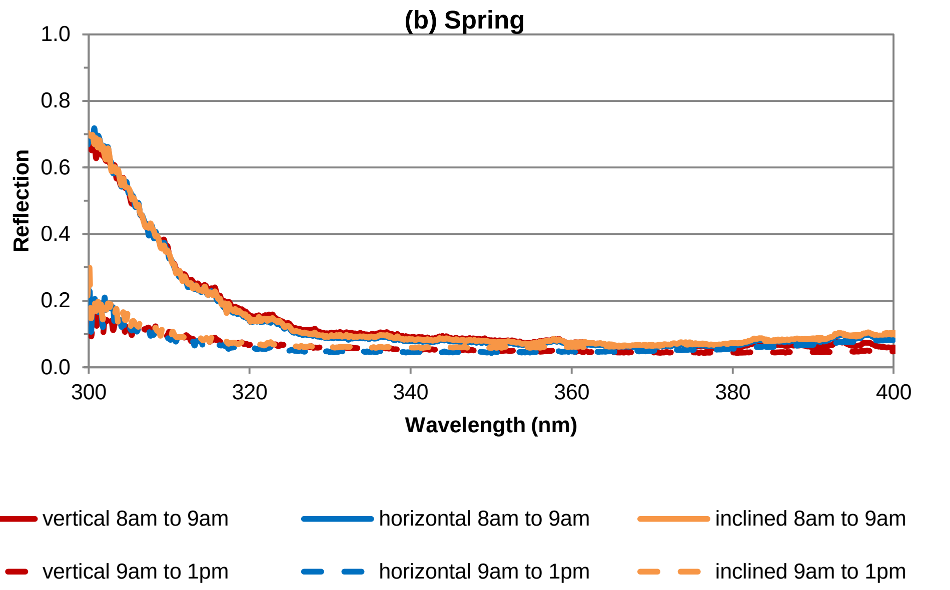


Figure 7.56 - Average reflection for medium blue trapezoidal for horizontal and north facing vertical and inclined surfaces for varying SZA and SAA in (a)Winter 2010 and (b) Spring 2010.

7.3 UVI charts

7.3.1 Zinc aluminium trapezoidal

7.3.1.1 Autumn 2008

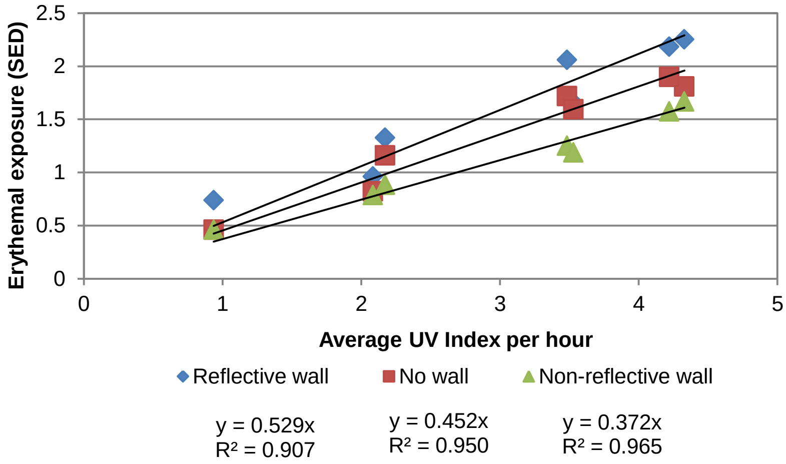


Figure 7.57 – All dosimeters average erythemal exposure measured in SED versus UV Index for zinc aluminium trapezoidal, non-reflective and no wall in Autumn 2008.

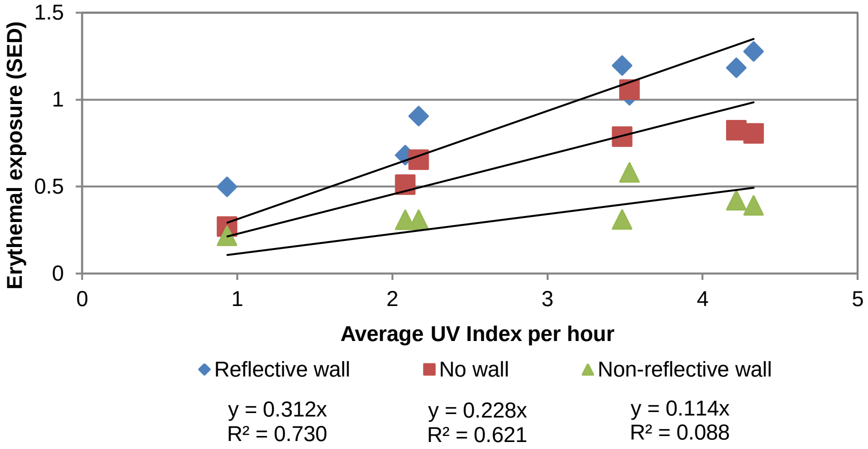


Figure 7.58 – Face chest and ears dosimeters average erythemal exposure measured in SED versus UV Index for zinc aluminium trapezoidal, non-reflective and no wall in Autumn 2008.

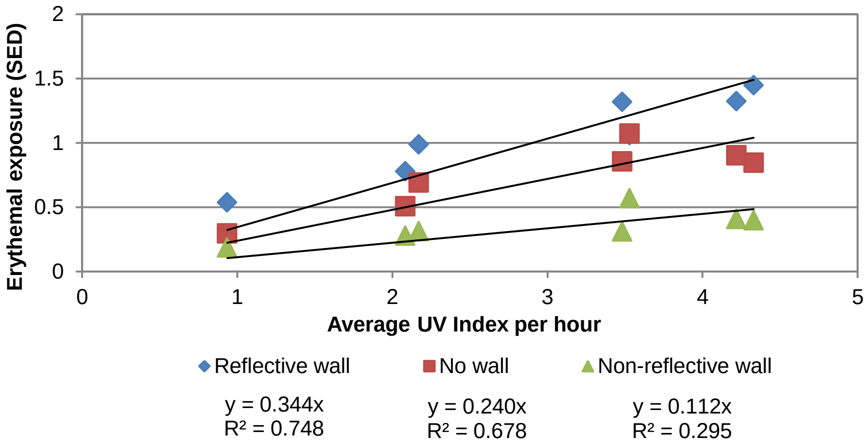


Figure 7.59 - Face dosimeters average erythemal exposure measured in SED versus UV Index for zinc aluminium trapezoidal, non-reflective and no wall in Autumn 2008.

7.3.1.2 Spring 2008

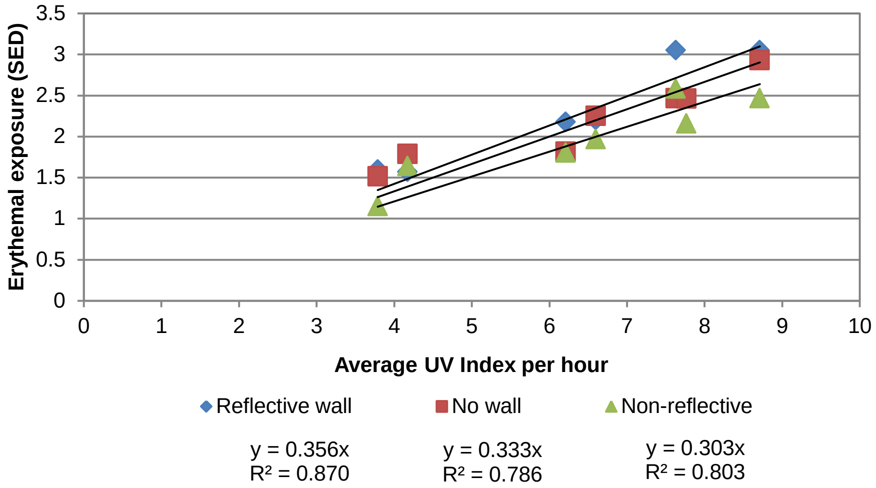


Figure 7.60 – All dosimeters average erythemal exposure measured in SED versus UV Index for zinc aluminium trapezoidal, non-reflective and no wall in Spring 2008.

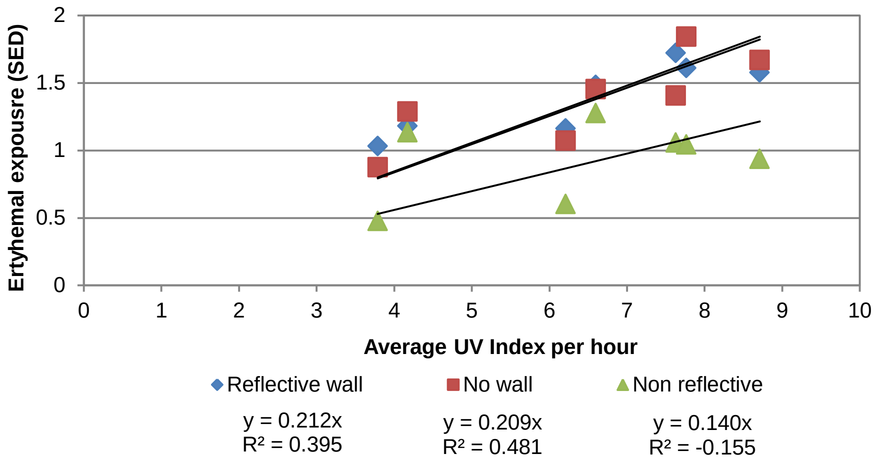


Figure 7.61 - Face chest and ears dosimeters average erythemal exposure measured in SED versus UV Index for zinc aluminium trapezoidal, non-reflective and no wall in Spring 2008.

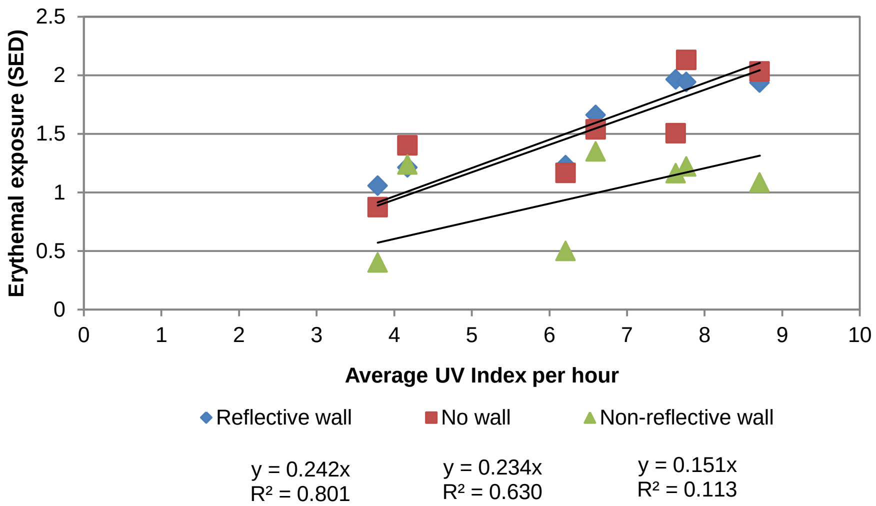


Figure 7.62 - Face dosimeters average erythemal exposure measured in SED versus UV Index for zinc aluminium trapezoidal, non-reflective and no wall in Spring 2008.

7.3.1.3 Spring 2010

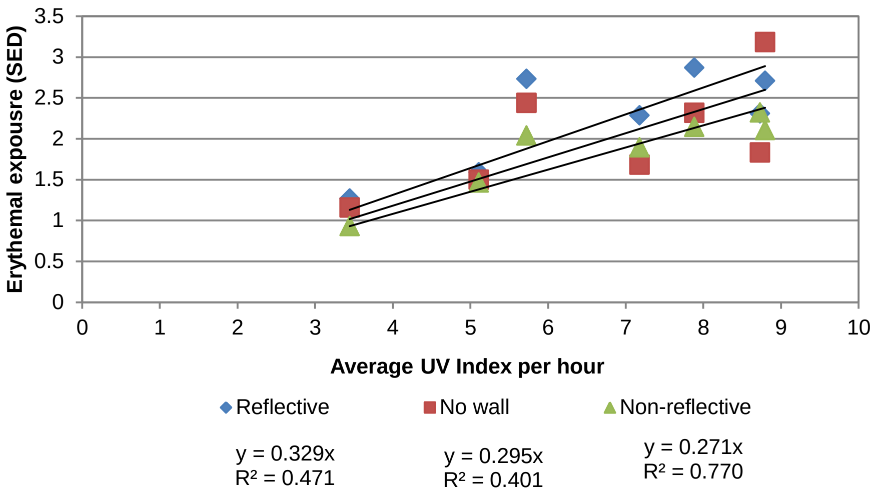


Figure 7.63 – All dosimeters average erythemal exposure measured in SED versus UV Index for zinc aluminium trapezoidal, non-reflective and no wall in Spring 2010.

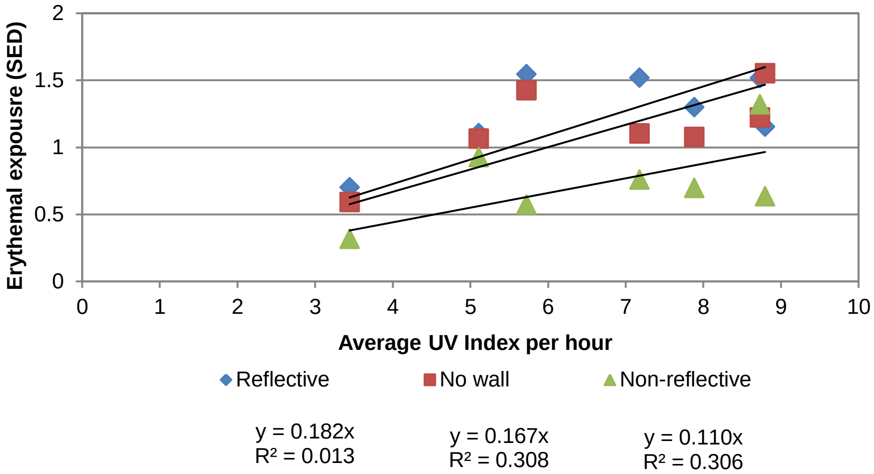


Figure 7.64 - Face chest and ears dosimeters average erythemal exposure measured in SED versus UV Index for zinc aluminium trapezoidal, non-reflective and no wall in Spring 2010.

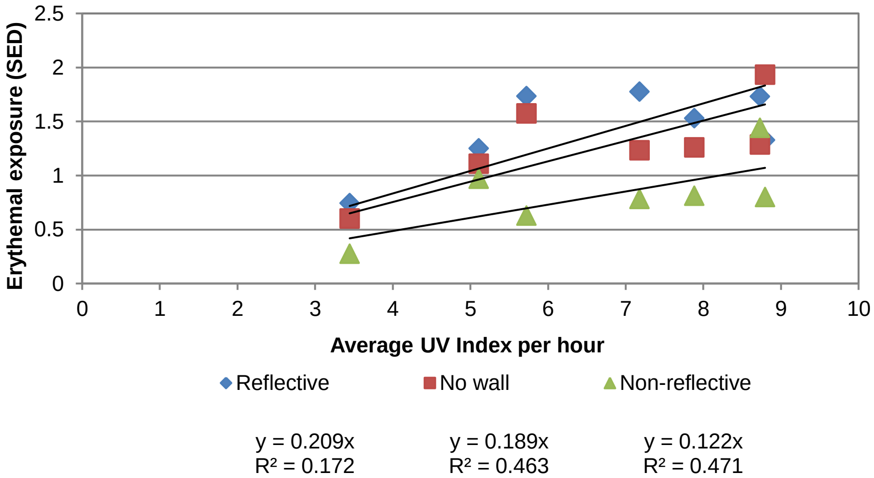


Figure 7.65 - Face dosimeters average erythemal exposure measured in SED versus UV Index for zinc aluminium trapezoidal, non-reflective and no wall in Spring 2010.

7.3.1.4 Autumn 2009 (corners)

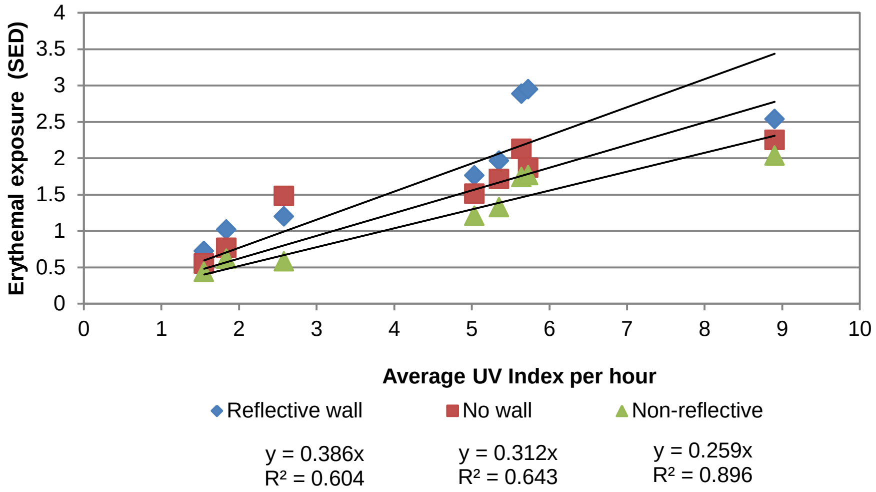


Figure 7.66 - All dosimeters average erythemal exposure measured in SED versus UV Index for zinc aluminium trapezoidal, non-reflective and no corner in Autumn 2008.

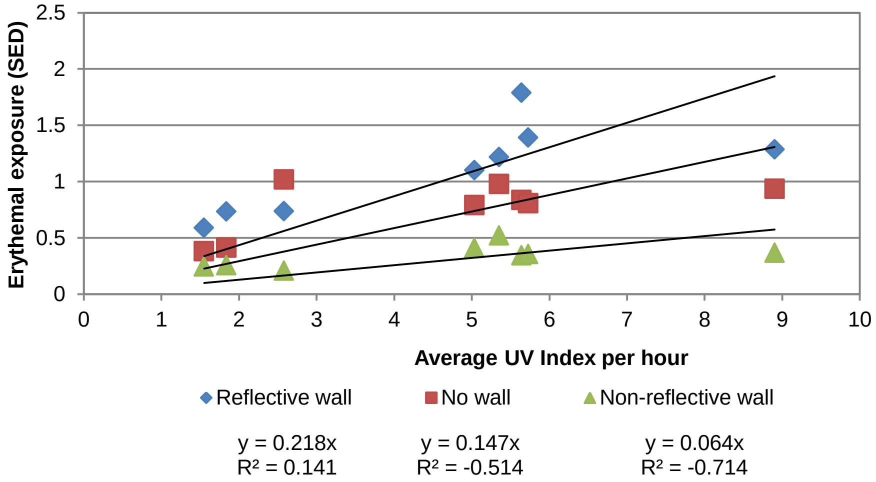


Figure 7.67 – Face chest and ears dosimeters average erythemal exposure measured in SED versus UV Index for zinc aluminium trapezoidal, non-reflective and no corner in Autumn 2008.

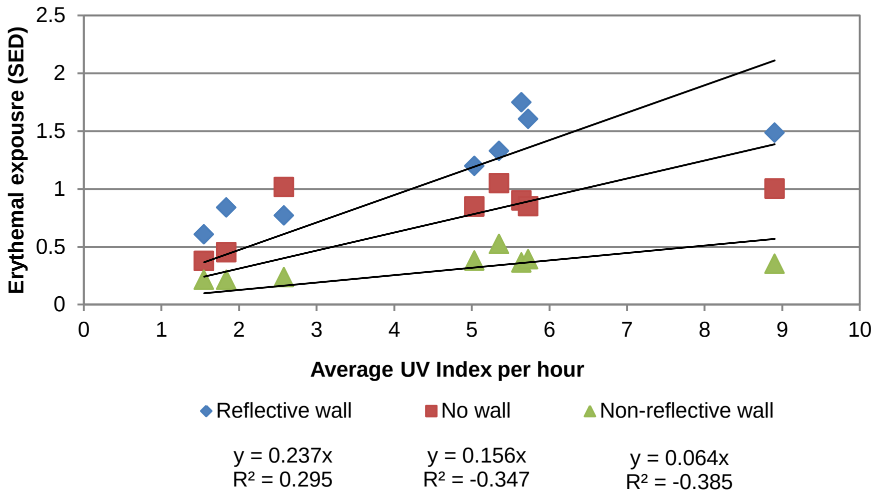


Figure 7.68 - Face dosimeters average erythemal exposure measured in SED versus UV Index for zinc aluminium trapezoidal, non-reflective and no corner in Autumn 2008.

7.3.2 Zinc aluminium corrugated

7.3.2.1 Early spring 2008

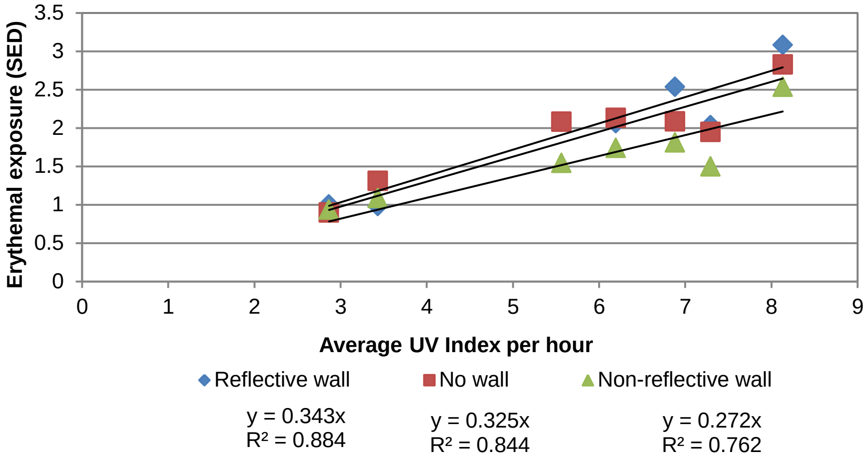


Figure 7.69 - All dosimeters average erythemal exposure measured in SED versus UV Index for zinc aluminium corrugated, non-reflective and no wall in early Spring 2008.

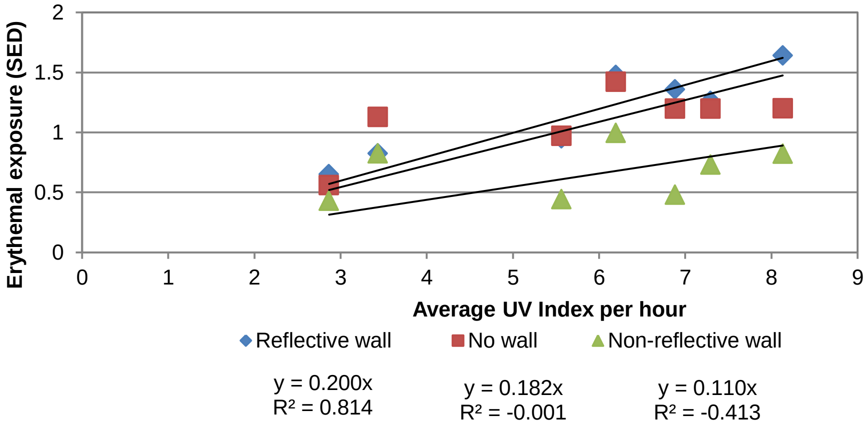


Figure 7.70 – Face chest and ears dosimeters average erythemal exposure measured in SED versus UV Index for zinc aluminium corrugated, non-reflective and no wall in early Spring 2008.

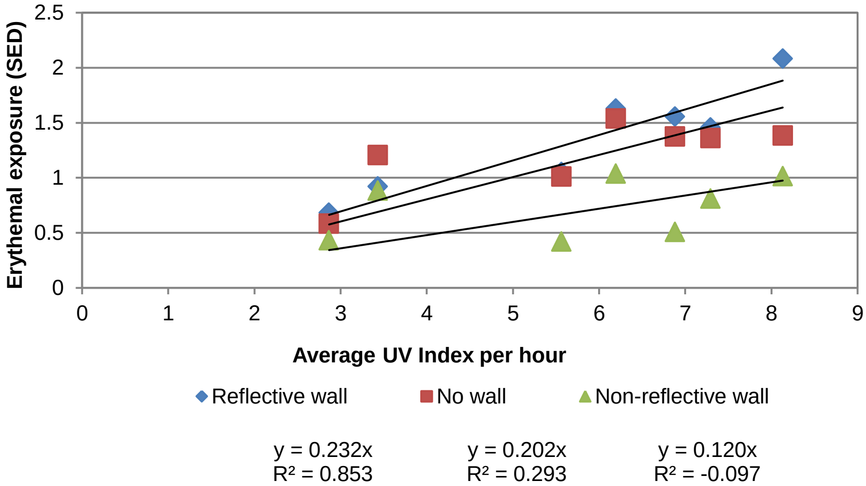


Figure 7.71 - Face dosimeters average erythemal exposure measured in SED versus UV Index for zinc aluminium corrugated, non-reflective and no wall in early Spring 2008.

7.3.3 Pale green trapezoidal

7.3.3.1 Autumn 2008

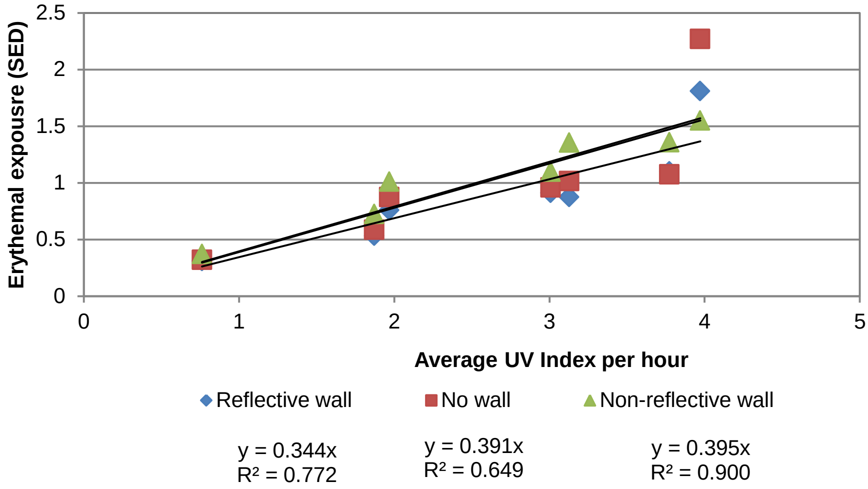


Figure 7.72 - All dosimeters average erythemal exposure measured in SED versus UV Index for pale green trapezoidal non-reflective and no wall in Spring 2008.

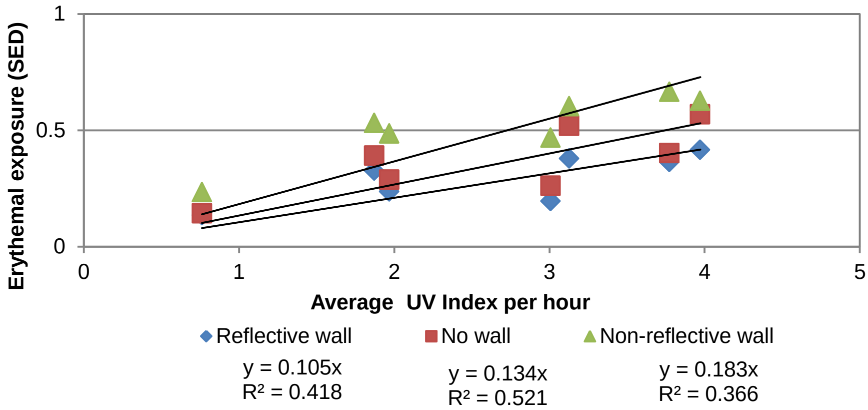


Figure 7.73 – Face chest and ears dosimeters average erythemal exposure measured in SED versus UV Index for pale green trapezoidal non-reflective and no wall in Spring 2008.

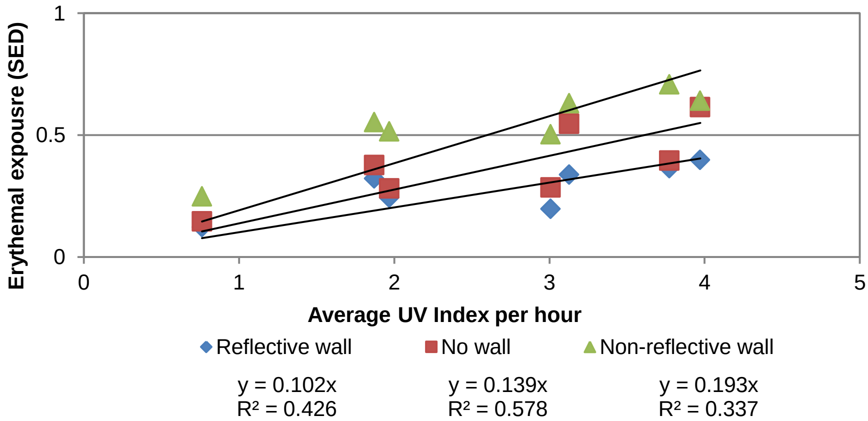


Figure 7.74 - Face dosimeters average erythemal exposure measured in SED versus UV Index for pale green trapezoidal non-reflective and no wall in Spring 2008.

7.3.3.2 Autumn 2009 (corner)

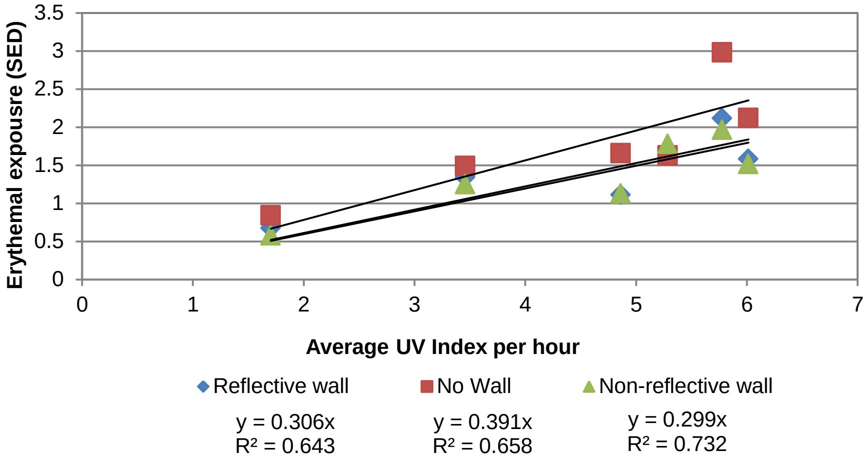


Figure 7.75 - All dosimeters average erythemal exposure measured in SED versus UV Index for pale green trapezoidal non-reflective and no corner in Spring 2009.

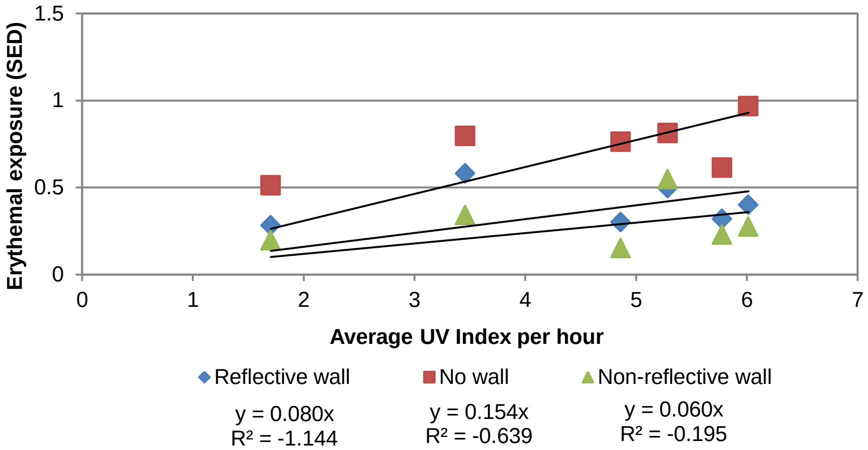


Figure 7.76 - Face chest and ears dosimeters average erythemal exposure measured in SED versus UV Index for pale green trapezoidal non-reflective and no corner in Spring 2009.

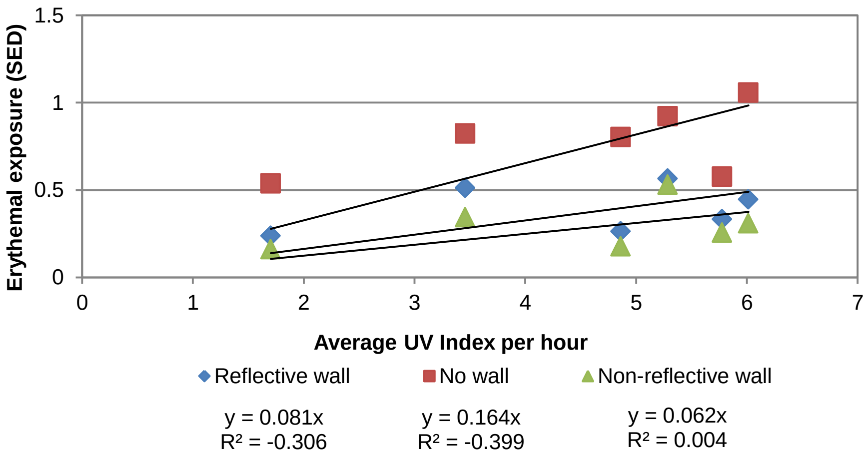


Figure 7.77- Face dosimeters average erythemal exposure measured in SED versus UV Index for pale green trapezoidal non-reflective and no corner in Spring 2009.

7.3.4 Cream trapezoidal

7.3.4.1 Autumn 2008

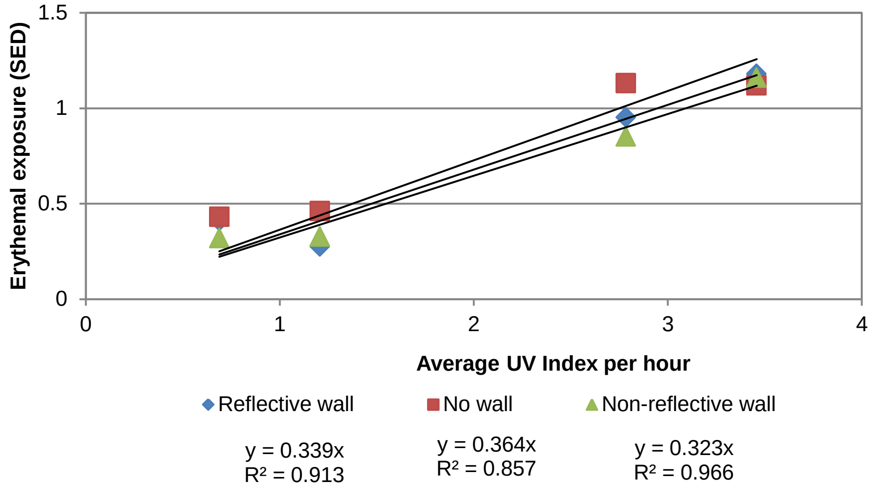


Figure 7.78 - All dosimeters average erythemal exposure measured in SED versus UV Index for cream trapezoidal non-reflective and no wall in Autumn 2008.

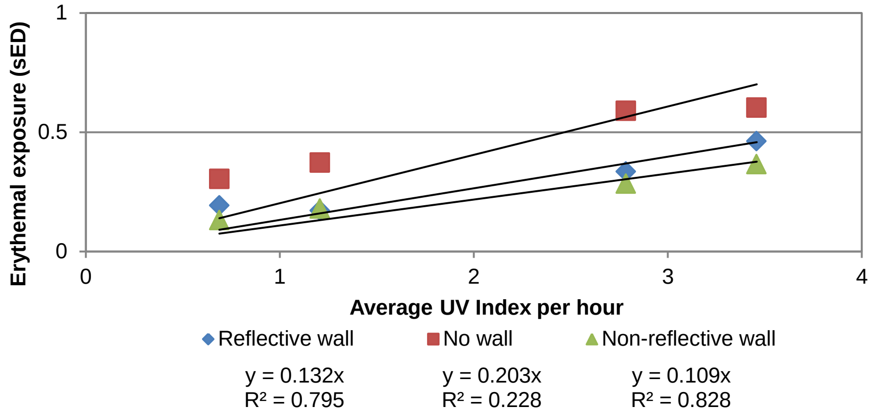


Figure 7.79 - Face chest and ears dosimeters average erythemal exposure measured in SED versus UV Index for cream trapezoidal non-reflective and no corner in Autumn 2008.

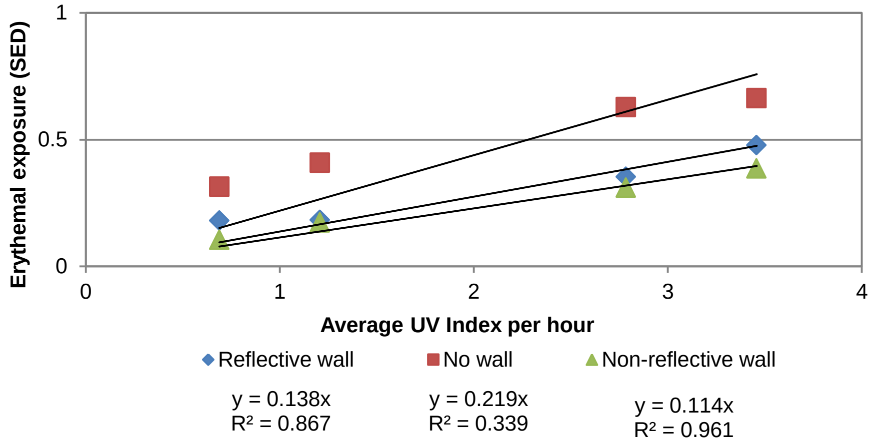


Figure 7.80 - Face dosimeters average erythemal exposure measured in SED versus UV Index for cream trapezoidal non-reflective and no corner in Autumn 2008.

7.3.4.2 Winter 2008

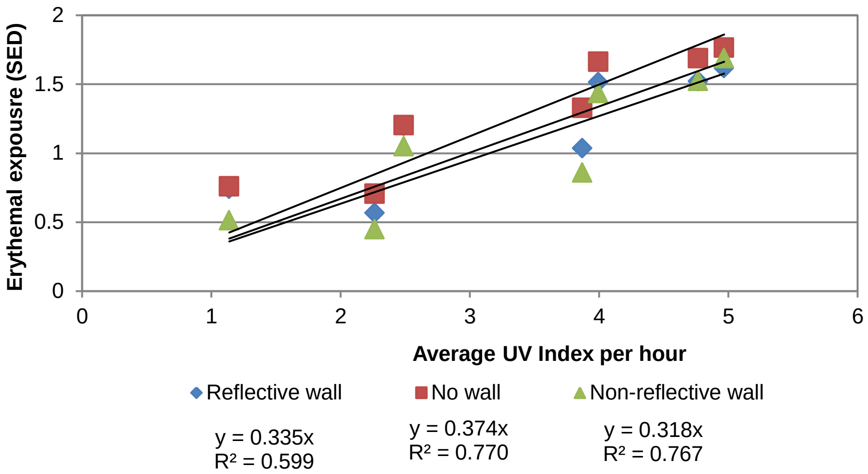


Figure 7.81- All dosimeters average erythemal exposure measured in SED versus UV Index for cream trapezoidal non-reflective and no wall in Winter 2008.

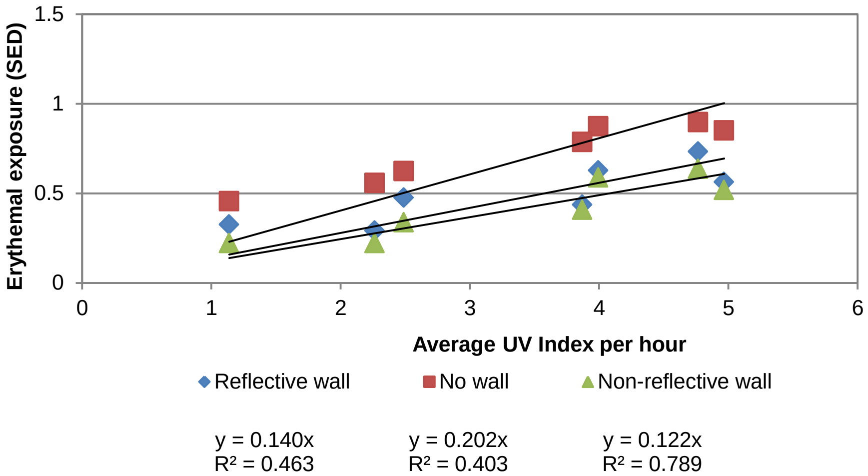


Figure 7.82 - Face chest and ears dosimeters average erythemal exposure measured in SED versus UV Index for cream trapezoidal non-reflective and no corner in Winter 2008.

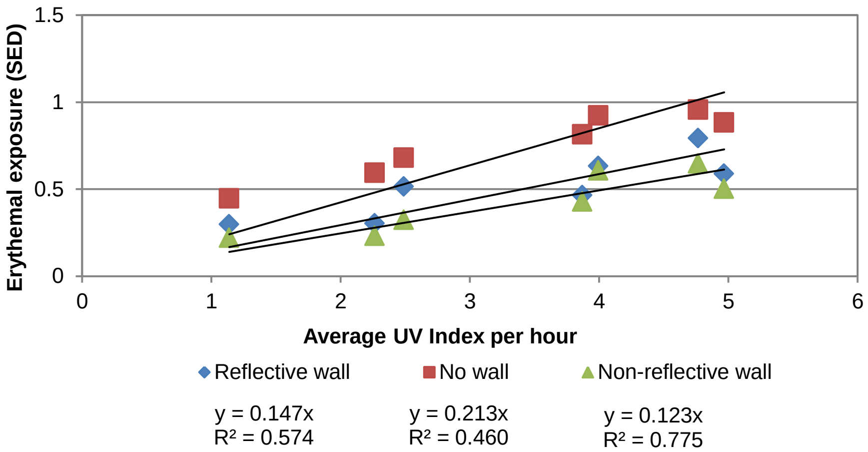


Figure 7.83 - Face dosimeters average erythemal exposure measured in SED versus UV Index for cream trapezoidal non-reflective and no corner in Winter 2008.

7.3.5 Zinc aluminium finished surface walls

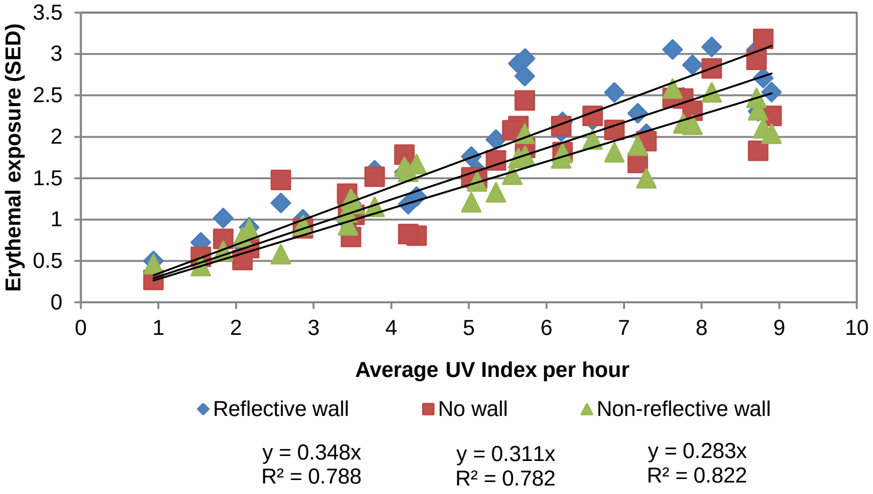


Figure 7.84 - All dosimeters average erythemal exposure measured in SED versus UV Index for all zinc aluminium finished wall, non-reflective and no wall (or corner).

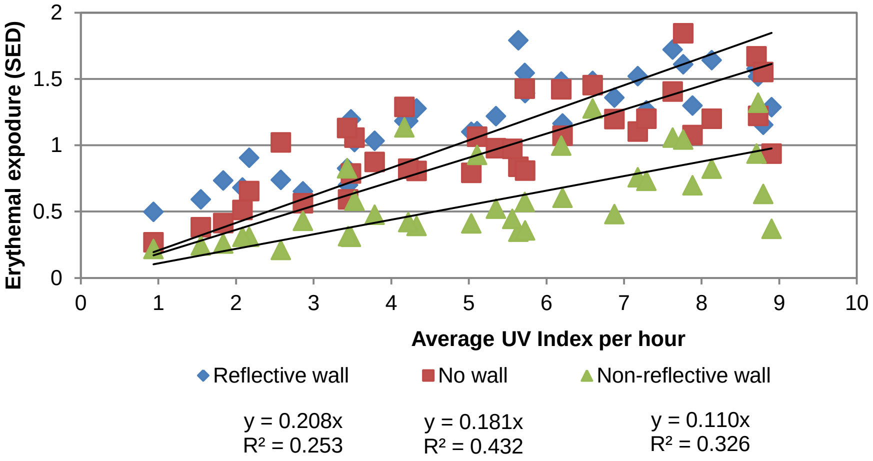


Figure 7.85 - Face chest and ears dosimeters average erythemal exposure measured in SED versus UV Index for zinc aluminium finished wall, non-reflective and no wall (or corner).

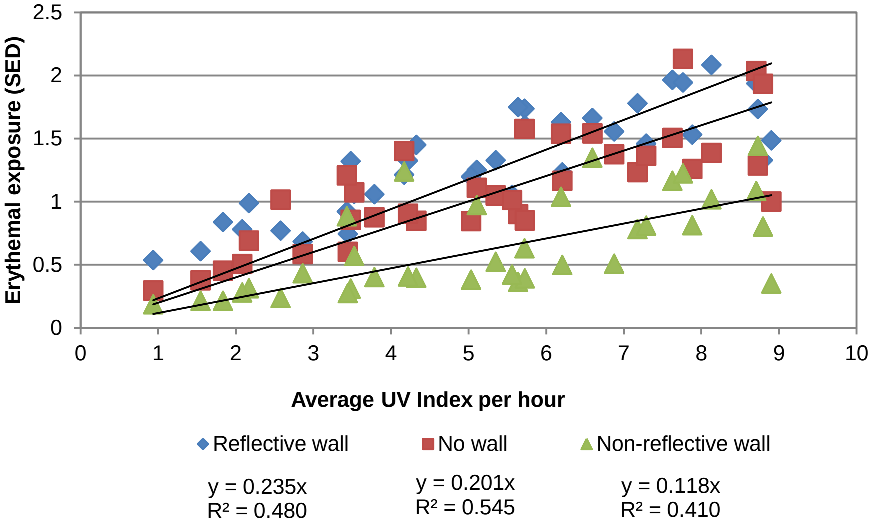


Figure 7.86 - Face dosimeters average erythemal exposure measured in SED versus UV Index for zinc aluminium finished wall, non-reflective and no wall (or corner).

7.3.6 Paint coated surfaces

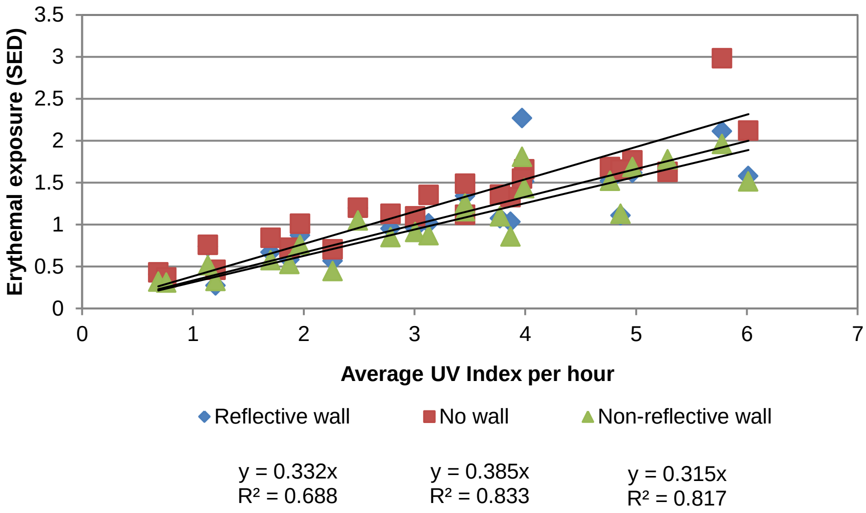


Figure 7.87 - All dosimeters average erythemal exposure measured in SED versus UV Index for paint coated wall, non-reflective and no wall (or corner).

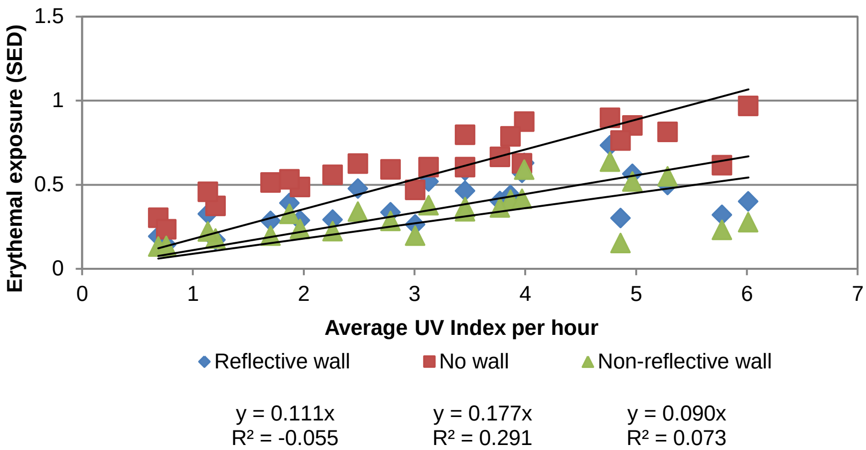


Figure 7.88 - Face chest and ears dosimeters average erythemal exposure measured in SED versus UV Index for paint coated wall, non-reflective and no wall (or corner).

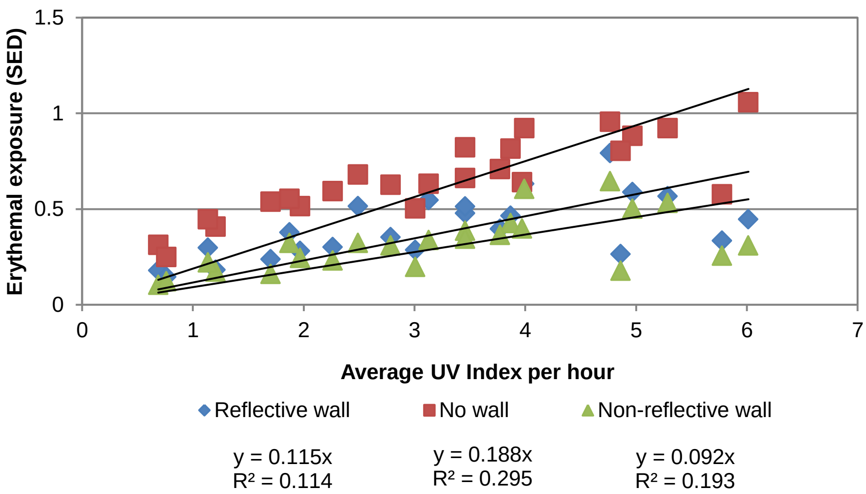


Figure 7.89 - Face dosimeters average erythemal exposure measured in SED versus UV Index for paint coated wall, non-reflective and no wall (or corner).

8 Previously Published Articles

The following are refereed published articles pertaining to this thesis as submitted in revised form to the indicated journals:

8.1 Turner, J, Parisi, A V & Turnbull, D J (2008) Reflected solar radiation from horizontal, vertical and inclined surfaces: Ultraviolet and visible spectral and broadband behaviour due to solar zenith angle, orientation and surface type, Journal of Photochemistry and Photobiology B: Biology, vol 92, pp. 29-37.

8.2 Turner, J & Parisi, A V (2009) Measuring the influence of UV reflection from vertical metal surfaces on humans, Photochemical & Photobiological Sciences, 8 (1). pp. 62-69.

Information presented in this thesis has been also presented as Abstract-in-Proceedings at the following conferences:

Turner, Joanna and Parisi, Alfio (2008) Characterising the influence on human UV exposures due to reflective vertical surfaces. In: 2008 American Society for Photobiology Symposia, 20-25 June 2008, Burlingame, California.

Turner, Joanna and Parisi, Alfio (2008) Measurement of ultraviolet radiation reflectivity: underestimating the influence of specular reflection in personal ultraviolet radiation exposure from non-horizontal surfaces. In: 18th National Congress of the Australian Institute of Physics, 30 Nov - 5 Dec 2008, Adelaide, Australia.

Turner, Joanna and Parisi, Alfio (2010) Understanding UV reflection in the urban environment. In Report of the NIWA UV Workshop: UV radiation and its effects, 7-9 May 2010, Queenstown, New Zealand.

Turner, Joanna and Parisi, Alfio (2010) Variations in UV exposure due to reflected UV radiation in the urban environment. In 35th Meeting for the American Society for Photobiology, 12-16 June 2010, Brown University, Providence, Rhode Island.

Turner, Joanna and Parisi, Alfio (2010) Ultraviolet reflection and outdoor workers: Why warm seasons have less influence on reflected UV exposures than cool seasons. In 19th National Australian Institute of Physics Congress, 5-9 Dec 2010, Melbourne, Australia.

8.1 Reflected solar radiation from horizontal, vertical and inclined surfaces: Ultraviolet and visible spectral and broadband behaviour due to solar zenith angle, orientation and surface type

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Abstract

Ultraviolet (UV) radiation affects human life and UV exposure is a significant everyday factor that individuals must be aware of to ensure minimal damaging biological effects to themselves. UV exposure is affected by many complex factors. Albedo is one factor, involving reflection from flat surfaces. Albedo is defined as the ratio of reflected (upwelling) irradiance to incident (downwelling) irradiance and is generally accepted only for horizontal surfaces. Incident irradiance on a non horizontal surface from a variety of incident angles may cause the reflectivity to change. Assumptions about the reflectivity of a vertical surface are frequently made for a variety of purposes but are rarely quantified. As urban structures are dominated by vertical surfaces, using albedo to estimate influence on UV exposure is limiting when incident (downwelling) irradiance is not normal to the surface. Changes to the incident angle are affected by the solar zenith angle, surface position and orientation and surface type. A new characteristic describing reflection from a surface has been used in this research. The ratio of reflected irradiance (from any surface position of vertical, horizontal or inclined) to global (or downwelling) irradiance (RRG) has been calculated for a variety of metal building surfaces in winter time in the southern hemisphere for both the UV and visible radiation spectrum, with special attention to RRG in the UV spectrum. The results show that the RRG due to a vertical surface can exceed the RRG due to a horizontal surface, at smaller solar zenith angles as well as large solar zenith angles.

The RRG shows variability in reflective capacities of surface according to the above mentioned factors and present a more realistic influence on UV exposure than albedo for future investigations. Errors in measuring the RRG at large solar zenith angles are explored, which equally highlights the errors in albedo measurement at large solar zenith angles.

Keywords: albedo, RRG, vertical surfaces, UV radiation, visible, solar zenith angle

Introduction

Exposure to biologically effective ultraviolet (UV) radiation can be beneficial to human health in the form of initiating pre-vitamin D_3 formation [1] and detrimental; such as erythema, skin cancer, ocular damage and more [2]. UV exposure is specific to the formation of the above health effects and much research has been conducted to measure and model UV exposure. UV radiation is influenced by (and UV exposure modelling must take into account) many atmospheric factors; including solar zenith angle, altitude, latitude, ozone, clouds, aerosols, albedo (reflectivity) [3,4] and personal factors; including occupation and personal behaviour [5-8].

Albedo is defined as the ratio of reflected (upwelling) irradiance to incident (down welling) irradiance for horizontal surfaces [9]. A surface that varies from a horizontal position but is still exposed to downwelling irradiance (to be referred to as global irradiance in this paper) can still produce reflected irradiance from the surface to the immediate environment. Due to the nature of the definition of albedo, this type of reflectivity cannot be assumed to be equivalent to albedo as it is dependent on the surface orientation and direction, solar zenith angle and type of surface, all of which contribute changes in the angle of incident UV radiation. If albedo is used to approximate this type of reflectivity for non horizontal surfaces, then contributions of such reflectivity to UV exposures to an individual could either be underestimated or overestimated. In the complex nature of the human environment, particularly urban environments which are dominated by vertical surfaces, understanding the interaction of reflected irradiance from vertical surfaces (as well as horizontal and inclined) will be important for health and safety issues for outdoor workers.

Previous work on reflectivity includes the investigation of the albedo of horizontal surfaces [9-12] as well as inclined surfaces such as snow covered mountain sides [13-14]. Irradiances on inclined surfaces affected by surrounding albedo have been previously explored [15-17]. Investigation of the biological effectiveness of the contribution to personal UV exposures due to the albedo of different horizontal and inclined surfaces has been investigated [18-20]. These effects are particularly important for outdoor workers' who should be aware of the contribution to UV exposures from such surfaces due to everyday working conditions [21]. The Guidance Note for the Protection of Workers from the Ultraviolet Radiation in Sunlight [21], specifies that workers be aware of the reflection of shiny metallic surfaces in the worker's vicinity. However, little information is available about the reflective capabilities of global UV irradiances from vertical surfaces in the vicinity of outdoor workers. The albedo of vertical surfaces has been briefly investigated for glass surfaces, along with the effect on diffuse UV due to the presence of walls [20]. Other studies mention albedo due to vertical surfaces in terms of modelling UV exposure but do not define the type of reflection of the global radiation from that surface [22]. Global irradiance will vary according to the factors that influence the incident angle of UV irradiance on a surface. Investigation of the UV irradiance received by vertical surfaces has been carried out [11,19,23]. Webb et al. [24] determined a relationship between vertical and horizontal irradiances. This research found that when solar zenith angles are large and the vertical surface is facing the direction of the sun, the vertical surface will receive more irradiance than a horizontal surface.

The study for horizontal albedo of roofing material by Lester and Parisi [18] shows high albedo recorded for shiny and coated horizontal surfaces, but does not consider vertical surfaces. However, in many industrial work sites, it can be commonplace to use the metal roof cladding as wall cladding. In urban residential areas, coated metal surfaces are used for fencing and both coated and shiny surfaces can be used for garden sheds or garages. This paper will compare the ratio of reflected irradiance to global irradiance (RRG) due to vertical and inclined surfaces to the albedo of a horizontal surface, by considering both the spectral and broadband RRG for visible and UV radiation. The paper will consider the variations of RRG due to solar zenith angle, orientation of the vertical plane and different metal surface types. Since albedo is quantitatively the same as the RRG on a horizontal surface, the term RRG will be used instead of albedo, unless referring specifically to referenced albedo measurements.

Methodology

The measurements were carried out on an archery field at the University of Southern Queensland, Toowoomba, Australia (27.5° S, 151.9° E). A metal frame was constructed to support a 1 m × 1 m size vertical sheet, of either a trapezoidal profile or corrugated profile sheet metal, to simulate the exterior wall of a building or a fence. A secondary piece of sheet metal of the same size was attached to the other side of this metal frame, inclined at 35º from the horizontal, simulating the sheet metal on the roof of a building. Both sheets were separated by the frame with sufficient distance between each sheet to prevent shading.

Eight types of trapezoidal metal sheeting and two types of corrugated metal sheeting were used (supplied by Metroll, Toowoomba). The corrugated metal sheets consisted of one zinc aluminium coated steel surface and one cream coloured coated steel surface. The distance between the ridges on the corrugated steel waves was 7.8 cm and the height difference between a trough and a peak was 1.7 cm. The trapezoidal metal sheeting consisted of one zinc aluminium coated steel surface, six colour coated steel surfaces (cream, beige, pale green, blue, dark red and black) and one zinc aluminium coated steel surface applied with a heat reflective coating (supplied by The Australian Insulation Super Store, Brisbane). The height difference between the top and bottom of the trapezoidal profile was 2.9 cm. The distance between the centres of the high ridges was 19 cm. Both sheet types have the ridges equally spaced across the surface and are symmetrical. The surface ridges are aligned top to bottom for inclined and vertical surfaces which holds with general building practices, and north to south for the horizontal surface.

Measurements of the spectral irradiances were made with an EPP2000 spectrometer (StellarNet, Florida, USA) with a detector based on a CCD array with a concave holographic grating with a groove density of 300 g/mm. The spectrometer has a slit width of 25 μm to give a resolution of less than 1 nm. Wavelength and irradiance calibration of the EPP2000 was undertaken by employing the 365 nm mercury spectral line and a 150 Watt quartz halogen lamp with calibration traceable to the National Physical Laboratory, UK standard. A two meter fibre optic cable connects a cosine receptor to the input of the housing for the array. The EPP2000 measured spectral irradiance from 300 nm to 700 nm in 0.5 nm steps. The integration time was 24 ms and averaged over 25 scans. The receptor was held in place using a lab stand with a 0.5 m arm and clamp. The arm held the receptor away from the main body of the lab stand, therefore reducing the amount of shadow that might fall on the metal sheeting during measurement. The lab stand, arm and clamp were adjustable so that the RRG of the horizontal, vertical and inclined surfaces was recorded at 0.5 m from the surface of the metal sheeting, with the sensor facing along the normal to each type of surface. The distance of 0.5 m was chosen because this would be the approximate arm's length distance a person would be from the metal surface if they were working in a building situation, such as construction of a wall or roof. The distance of 0.5 m was tested to determine if the sky view beyond the sheet would affect the measurements. The test compared the reflectivity at distances that were close enough to the sheet so that the cosine receptor would not receive any irradiance other than that from the sheet, to that at longer distances. The distances employed were 0.1 m, 0.2 m, 0.3 m, 0.4 m, 0.5 m and 1.0 m. It was found that for surfaces facing the sun, the sky view had little effect on the RRG recorded. As the distance between the surface and sensor increased, the spectral RRG decreased. The sky view only affected surfaces that were facing away from the sun, by increasing the spectral RRG as the distance between the surface and sensor increased. For these surfaces, when direct sunlight fell on the sensor, the data collected was eventually discarded. Data that was collected for these surfaces usually produced an RRG greater than 1.0, indicating the data was flawed. Thus the decision to choose a distance of 0.5 m from the surface was the most practical distance for construction workers, for this current study.

To account for the solar zenith angle (SZA) four series of measurements were carried out for a SZA range over a day between 35.3º and 73.4º for one sheet metal type. Early morning measurements began at 8 am local time, mid-morning measurements began at 10 am, midday measurements at noon and mid-afternoon measurements at 2 pm. Each series of measurements lasted approximately forty minutes. Each measurement made had the local time recorded, so that the appropriate SZA could be calculated.

In order to be consistent with the orientation, the metal frame was placed so that the vertical face was oriented towards geographical north initially (and therefore the inclined face was oriented to the south).The horizontal sheet was placed a short distance away from the metal frame to prevent shading. The metal frame was rotated and measured with the vertical face oriented to each of the west, south and east (the inclined face was oriented to the east, north and west). In the Southern Hemisphere, the north facing surface receives the most UV irradiance compared to surfaces facing west, south and east.

The spectral RRG was measured by recording the global spectral irradiance on a horizontal plane, then recording the reflected spectral irradiance for a given surface and taking the ratio of the spectral irradiances at each wavelength. To measure the reflected spectral irradiance, the EPP receiver was oriented to the normal of the reflecting surface at an average distance of 0.5 m. Each different oriented surface was measured for global spectra and reflected spectra, at each position (vertical, horizontal and inclined) throughout the day. Each measurement was repeated to allow averaging of the results.

The average RRG_{UVB} was determined by integrating the spectral data from 300 nm to 320 nm in 0.5 nm increments for each reflected and global spectral irradiance measurement before calculating the ratio. The RRG was then averaged according to the influencing factors: surface type, position, orientation and SZA.

Shading to the sensor due to the surface itself did not occur, due to the measurement procedure. The affect of shading to the RRG was not explored as it was outside the scope of the current investigation. The effect of shading will be a suitable future extension of this investigation.

Results

Spectral RRG due to surface type and position

The spectral behaviour of the RRG_{UV} and $RRG_{visible}$ for five of the eight trapezoidal surfaces is shown in Figure 1 for a SZA range of 35.3º to 47.6º. The three colours not included had the same spectral RRG as already represented surfaces and will be discussed later. The cream and zinc aluminum corrugated surfaces produced very similar spectral RRG as the cream and zinc aluminium trapezoidal surfaces.

The zinc aluminium vertical metal surface is the only type that reflects uniformly in the UV wavelengths at 0.30 RRG_{UV} (at a SZA range of 35.3º to 47.6º), which is significantly different to that of the other surfaces in the UV. An RRG_{UV} of 0.30 is significant, especially when considered in comparison to albedo due to natural horizontal surfaces, such as grass: 0.016 to 0.02 (at 300 nm and 400 nm respectively) [10] and sand: 0.09 erythemal albedo to 0.24 average UV albedo [12] and 0.14 to 0.24 (300 nm to 400 nm respectively) [10]. The colour coated and heat reflective coated metal surfaces have the same spectral RRG_{UV} , except for the black surface which is lower.

The white based surfaces (heat reflective coated, cream and pale green) have a higher RRG_{UV} of 0.1 to 0.2 in the shorter UV wavelengths (the spectral RRG_{UV} decreasing as wavelengths increase) until about 380 nm, where it then starts to increase into the visible spectrum. This increase is up to 0.15 for the heat reflective and cream coated surfaces. The maximum $RRG_{visible}$ occurs within the 500 nm to 600 nm range, for all surfaces except the black. The beige trapezoidal surface had the same spectral RRG as the cream trapezoidal surface, while the red and blue trapezoidal surfaces had the same spectral RRG as the black trapezoidal surface. This may be attributed to red and blue being dark based colours. Black trapezoidal has the most consistent RRG across the UV and visible spectrums for a vertical surface, but the spectral RRG decreases over increasing wavelengths for the visible spectrum. The low $RRG_{visible}$ is explained by the tendency of dark surfaces to absorb radiation rather than reflect.

Figure 2 shows four types of metal surfaces, (a) zinc aluminium and black trapezoidal and (b) cream and pale green trapezoidal, at SZAs of 35.3º to 47.6º during winter noon, for horizontal, vertical and inclined planes. The zinc aluminium surface reveals that the spectral RRG_{UV} on a vertical plane is higher by 0.02 to 0.04 than the spectral RRG_{UV} on the horizontal plane. Additionally the spectral RRG_{UV} due to the inclined surface is higher than the spectral RRG_{UV} due to the vertical plane by about 0.1. This is a large variance from the spectral RRG_{UV} due to the horizontal plane. The black surface has a spectral RRG_{UV} on the vertical plane at 0.01 to 0.06 higher than the horizontal plane. This is also shown to occur for cream and pale green surfaces. This behaviour was also observed on the beige, blue and red trapezoidal and cream corrugated surfaces. The only surfaces where this was not predominantly observed was the heat reflective coated trapezoidal and the zinc aluminium corrugated, where both vertical and horizontal surfaces appeared to have the same spectral RRG in the UV spectrum up until 380 nm. The visible spectrum was not observed to have the same behaviour, with the horizontal spectral $RRG_{visible}$ greater than vertical spectral $RRG_{visible}$ for all surfaces except for the beige, red and blue trapezoidal surfaces.

Spectral RRG due to SZA

Changing the time of day and therefore the SZA shows very different spectral RRG behaviour, particularly for the zinc aluminium surface. Figure 3 (a) shows measurements at 72.6º, 72.2º, 53.5º, 46.2º and 55.4º for vertical zinc aluminium trapezoidal surface on a north facing vertical plane. Early morning reveals the rapid change as the SZA decreases. The spectral RRG_{UV} values at 72º are larger than 0.5 over all wavelengths.

RRG values of 1.0 or above 1.0 are indicated in Figure 3. However, it is unlikely that these are accurate RRG values. Analysis of the direct and diffuse UV component of global irradiance values at large solar zenith angles has been carried out [25-26] and these components of the global irradiance can affect RRG values at particularly large SZA. The global irradiance is measured as the down-welling irradiance from the hemispherical sky-view above the receptor. Depending on the SZA, this global irradiance contains little to no direct UV (at large SZAs) and can be entirely made up of diffuse irradiance [25]. A measurement from a reflective surface facing the sun at large SZA is likely to record this same diffuse measurement as the global irradiance measurement, and additionally a reflected direct UV component. If the direct UV component is measured as a part of the reflective component, but not of the global component of a total RRG measurement, the RRG result will appear to be 1.0 or greater than 1.0. This is a wavelength specific characteristic. As the SZA decreases, the direct UV content of the global irradiance increases [26] and this effect observed at large SZAs slowly diminishes.

Spectral RRG due to orientation

The influence of the solar azimuth on the spectral RRG_{UV} of a vertical zinc aluminium trapezoidal surface is shown in Figure 4. Figure 4 (a) shows the spectral RRG_{UV} for north, west, south and east for mid morning (SZA range of 54º to 49º), while Figure 4(b) shows the spectral RRG_{UV} for north, west, south and east for mid afternoon (SZA range of 54.9º to 61.5º). For mid morning, the maximum spectral RRG_{UV} occurs on the north vertical facing side, while mid afternoon, maximum spectral RRG_{UV} occurs on the west vertical facing side. In general, when the sun is not facing the vertical plane, the spectral RRG_{UV} remains the same for each orientation.

Average RRG for surface type and position

Figure 5 displays the average RRG_{UVB} (the average of the RRG_{UV} measured for each 0.5 nm step from 300 nm to 320 nm) for a zinc aluminium trapezoidal surface, for the entire day of orientation, position and SZA variations. The early morning RRG_{UVB} measurements (SZA range of 73.4º to 63.9º) are mostly greater than other times of the day (mid morning: 54º to 49º, midday: 46.1º to 47.6º and mid afternoon: 54.9º to 61.5º). The early morning west vertical RRG_{UVB} values are not available due to the sensor being exposed to direct sunlight at that time. This was due to the azimuth of the sun rather than the height of the vertical plane not providing shade to the sensor. The same occurred for most south vertical plane RRG_{UVB} measurements. The midday east vertical RRG_{UVB} is missing due to the height of the vertical plane resulting in no shade to the sensor.

The greatest average RRG_{UVB} is recorded on the north inclined plane in the early morning. The inclined planes for the west and the north have the largest RRG_{UVB}, while the south and the east inclined RRG_{UVB} are still effective at greater than 0.15. There is greater variation between early morning and midday RRG_{UVB} on inclined planes, which is due to the SZA variation. Table 1 shows the average RRG_{UVB} for all metal surface types, comparing overall, vertical, horizontal and inclined surfaces.

Discussion

The RRG_{UV} is a significant characteristic of a reflecting surface. The RRG_{UV} is not the same as UV albedo. UV albedo is a useful tool in estimating increases or decreases to total UV exposure, but only for situations where the incoming radiation consisting of both direct and diffuse UV radiation is incident on a surface that is normal to this radiation, generally a horizontal surface. However, the content of direct and diffuse UV in global radiation changes according to SZA and azimuth, as well as surface type, position and orientation. For example, an industrial shed is being built with a shiny metal, with the entrance and main outside work area facing north. What effect does this wall have on the UV exposure of a worker at different times of the day? Albedo is no longer representative of the reflective capacity of a surface oriented at a position that does not receive both direct and diffuse UV radiation. A vertical surface with the sun at a small SZA would receive very little direct UV, but would still reflect diffuse UV. At the same SZA a horizontal surface will easily reflect both direct and diffuse UV radiation as they are both incident on the horizontal surface. To effectively quantify the influence of the reflective capacity of a surface at positions other than the horizontal, the RRG_{UV} has been defined and employed in this paper.

RRG_{UV} due to surface type and position

Figures 1 and 2 show the spectral distribution of the RRG_{UV} from a zinc aluminium trapezoidal surface. There is some photon noise present at the shorter wavelengths, but this does not affect the overall spectral distribution. The spectral RRG_{UV} measured due to vertical surfaces is in agreement with the work of Lester and Parisi [18] in which it was found that galvanised (zinc coated steel) corrugated metal at 305nm had an albedo of 0.27. The measured spectral RRG_{UV} is approximately 0.3 at most wavelengths in Figure 1, slightly higher than the albedo measured by Lester and Parisi.

The heat reflective coated surface can be compared to a previous study by Parker et al. [28] who analysed the same product, in which the UV reflectance was measured as 0.184 for a small 0.1 m × 0.1 m sample. Table 1 shows the average value of 0.19, although the spectral data in Figure 1 suggests the RRG_{UV} may actually be much lower than that measured by Parker et al. The authors of that study caution that this may be variable due to the nature of the measurements made.

Figure 2 shows vertical surfaces with greater spectral RRG_{UV} than horizontal surfaces, and this is replicated by all other surface types (not shown except for the beige, red and blue surfaces: these three surfaces have the same RRG_{UV} for horizontal and vertical surfaces at the same SZA).

The zinc aluminium corrugated surface (not shown) has a similar spectral RRG_{UV} on a vertical plane as the zinc aluminium trapezoidal surface and the averages observed in Table 1 suggest there is little difference between sheet metal structure, however the averages for cream trapezoidal and cream corrugated surfaces are different, with the corrugated cream surface reflecting an average of ten percent less than the cream trapezoidal. Coulson and Reynolds [11] suggests the structure of a surface that has many interstices is less capable at reflecting because of the likelihood of trapping photons within the structure itself (due to the ridges in the metal), however this does not explain why this is not observed for both metal structure types in a zinc aluminium finish. Perhaps in this case the shiny surface exceeds the ability of the corrugated structure to trap more photons than the trapezoidal and therefore both the trapezoidal and corrugated surfaces behave in the same reflecting manner. The metal sheeting is new and has not been affected by the weather and environment. A zinc aluminium metal sheeting that has been affected by time and environment may be very different in spectral and average RRG_{UV} characteristics.

The zinc aluminium surfaces appear to have the largest RRG_{UV} out of all the surfaces. This may be due to the shiny smooth finish of the surface. Roughness lowers the reflectance of surfaces [27] and painted or coated surfaces may be rougher at the particle level than steel. The expected RRG_{UV} values for vertical surfaces are suggested by Heisler and Grant [20], who state that most clean metals free of oxide and tarnish have an albedo of 0.3 to 0.55 within the UVB waveband.

RRG_{UV} due to SZA and solar azimuth

The position of the early morning sun means that direct UV is positioned to fall more directly on the north facing vertical plane, causing maximum reflection of the incident UV to the detector for a north facing orientation. A factor that may contribute to large RRG_{UV} values for large SZA in the early mornings is the lack of atmospheric interference from a clear sky, where condensation and particulate matter has fallen overnight and has not yet evaporated. By mid morning the SZA is nearly 20º less than the early morning values and the spectral RRG_{UV} has also decreased, averaging just over 0.3. At midday, the spectral RRG_{UV} remains around 0.3 however, the mid afternoon spectral RRG_{UV} drops below 0.3, despite being approximately at the same SZA as the mid morning value. This decrease is due to the change in azimuth from morning to afternoon, where the direct UV falling on the vertical surface has decreased due to the westerly progression of the sun through the sky. This was also observed by Webb et al. [24] when investigating irradiances falling on vertical planes. Figure 3 (b) on a north facing black trapezoidal surface, shows the behaviour of the zinc aluminium trapezoidal is not similar to that of the black coated surface, where the minimum spectral RRG observed is that at a SZA of 36.8º, while the afternoon and morning spectral RRG are somewhat greater.

Investigation of the cream, heat reflective and pale green trapezoidal surfaces, showed that the RRG_{UV} at a large SZA was always greater than RRG_{UV} values at smaller SZA, and that SZA values below 50º and above 35.3° tended to show the same spectral RRG_{UV} throughout the day, with just small variation between morning, midday and midafternoon values.

Comparing Figures 2 and 3 the vertical and horizontal spectral RRG_{UV} at large SZA, indicate that the vertical spectral RRG_{UV} is much larger than the horizontal spectral RRG_{UV} for most metal surfaces. For large SZA, a first glance at the results suggest the vertical spectral RRG_{UV} is almost double the horizontal spectral UV albedo for zinc aluminium (0.5 and 0.3 respectively) and light coloured coated surfaces (0.2 and 0.1), and more than double for dark coated surfaces (0.15 and 0.05). However, as outlined in the results, the RRG_{UV} values at large SZA may be overestimated, due to the components of the global UV irradiance being dominated by diffuse UV irradiance and very little direct UV irradiance. Thus, when the reflected UV is measured for a vertical surface at a large SZA oriented towards the sun, it is possible there is more direct UV present in the reflected UV irradiance than in the global irradiance. Hence the tendency to find some RRG_{UV} values greater than one at large SZA with surfaces oriented towards the sun. For dark coated surfaces, whilst the RRG_{UV} due to a vertical surface may be small, these are still considerably larger than the RRG_{UV} due to a horizontal surface. The same overestimation is likely to be occurring with even the dark coated surfaces, even if the values are not unrealistic. Comparing the RRG_{UVB} in Table 1 for horizontal and vertical surfaces suggests this may be a possibility where for even dark coated surfaces the RRG for vertical surfaces is quite large. Comparatively, the zinc aluminium surfaces have very little difference between average horizontal and vertical RRG, so it is uncertain how much overestimation really is occurring. It is possible that RRG values at large SZA will be negligible in influencing UV exposure to individuals, due to the attenuation of UV wavelengths at that time of day. Weihs et al., [13] found albedo values for inclined ground surfaces greater than 1.0 but only accounted for these values by concluding that directionality was the cause but did not explain the dynamics of directionality. It is interesting to note their albedo values were found for a SZA of 49°, a SZA much smaller than found in this study for RRG_{UV} values greater than 1.0. Altitude would have had a significant influence on their data and may explain the contrast to the data found in this study, as well as the different techniques used in measuring the albedo. To account for the RRG_{UV} at large SZA, further research will include global irradiance measurements to be investigated with the sensor directed towards the sun in addition to the downwelling (global) irradiance measurement, which is expected to show albedo or RRG_{UV} values greater than 1.0 are overestimations.

Average RRG_{UV}

Figure 5 is just one surface type of the ten investigated, yet it shows an interesting effect in the RRG_{UV} due to a horizontal surface. Despite the changing SZA, there is less variation in RRG_{UV} due to a horizontal surface than due to a vertical surface and the overall averages are also slightly less, even though the incident angle of the direct UV irradiance as a component of the global irradiance is changing. Additionally, the RRG_{UV} at large SZA due to a horizontal surface is larger than at noon. However, as in the case of the overestimation of RRG_{UV} for vertical surfaces at large SZA, the RRG_{UV} for horizontal surfaces at the same SZA may also be overestimated, with the global irradiance unlikely to account for all the direct UV irradiance that does fall on the horizontal surface. This would also be true for inclined surfaces at large SZA.

Taking all the daily data for each of the surface types and calculating a single RRG_{UVB} for all data, all horizontal data, all vertical data and all inclined data, it has been found the possible overestimation for large SZA is likely to have led to an overestimation of a daily average. This is apparent in the colour coated surface variation between the averages of horizontal and vertical RRG_{UVB} where vertical RRG_{UVB} are more than double the RRG_{UVB} on a horizontal surface. The zinc aluminium surfaces do not show this trend, and despite the earlier discussion on reflective capacity of zinc aluminium surfaces, it does not answer why the RRG_{UVB} for horizontal and vertical surfaces should be so similar but not for the coated surfaces. The only other possibility of explanation is the behaviour of the reflection itself, meaning specular reflection (reflecting at the boundary of the surface) or diffuse reflection (reflecting from particles below the surface). Until this overestimation is calculated, the average daily values of RRG_{UVB} are not likely to provide accurate information for current use.

What is apparent from Figure 5, despite the overestimation of RRG_{UV} values at large SZA, there appears to be a relationship between the SZA, the position of the surface, and the orientation surface and the measured RRG_{UV} values for this surface type. Further measurements will be carried out to determine a more accurate relationship between the RRG_{UV} and the influencing factors. Current modelling studies that calculate albedo in urban environments may benefit from calculating RRG instead of albedo. An example of such a model is that reported by Chimklai, Hagishima and Tanimoto [29] that modelled albedo for vertical surfaces, and found there was still differences between the observed albedo and modelled albedo despite extensive attention to detail in influencing factors. Additionally, the use of RRG instead of albedo could be used to produce more accurate models that determine UV exposure in urban environments. Extension of this work will include measuring the effects on total UV exposure to humans due to the presence of a vertical, inclined or horizontal surface.

Conclusions

For outdoor workers (such as construction workers) who spend time in the vicinity of vertical, horizontal or inclined metal surfaces, the RRG_{UV} may lead to an increase in UV exposure, particularly for those metal surfaces with a galvanised or zinc aluminium finish. Vertical metal planes facing the sun have higher RRG_{UV} at large SZAs than horizontal metal planes. Early morning or late afternoon sun may have more effect on a person if they are standing in the vicinity of such a surface, but UV exposure could equally be negligible due to attenuation at these solar zenith angles. The most common of these vertical surfaces in every day life are zinc aluminium or green coated surfaces, such as garden sheds and residential fencing. A person going about their usual activities outside in the garden could increase their overall UV exposure, if they are working in the vicinity of this type of vertical plane.

Prevention of overexposure of UV radiation to the everyday person, can be achieved by ensuring the person wears sun protective clothing and applies sunscreen, as well as hat and glasses. Workers in the construction industry should be advised of the RRG_{UV} of metal surfaces on vertical, horizontal and inclined planes and advised to protect themselves according to the guidelines outlined in the Guidance Note for the Protection of Workers from the ultraviolet radiation in sunlight [21].

This research has shown that in many cases the RRG_{UV} from vertical metal surfaces is not equivalent to the RRG_{UV} from a horizontal metal surface (also known as albedo) for a spectral distribution. RRG_{UV} from a vertical metal surface can exceed RRG_{UV} from a horizontal metal surface and is dependent on solar zenith angle, orientation and surface type. This may have considerable impact on UV exposure applications such as modelling, and direct impact on workers in the building industry and everyday life.

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Table 1 – Comparison of average RRG_{UVB} radiation over all metal surface types and all SZAs.

Metal Type	**Average RRG $_{UVB}$(300 nm – 320 nm)**			
	Overall	***Vertical***	***Horizontal***	***Inclined***
Zinc aluminium trapezoidal	0.32	0.28	0.28	0.39
Zinc aluminium corrugated	0.31	0.29	0.28	0.35
Beige trapezoidal	0.17	0.15	0.13	0.16
Cream trapezoidal	0.27	0.28	0.19	0.25
Cream corrugated	0.17	0.20	0.11	0.16
Blue trapezoidal	0.11	0.12	0.06	0.07
Heat reflective trapezoidal	0.19	0.21	0.14	0.17
Black trapezoidal	0.10	0.14	0.04	0.06
Red trapezoidal	0.11	0.14	0.04	0.07
Pale green trapezoidal	0.12	0.15	0.06	0.07

Figures

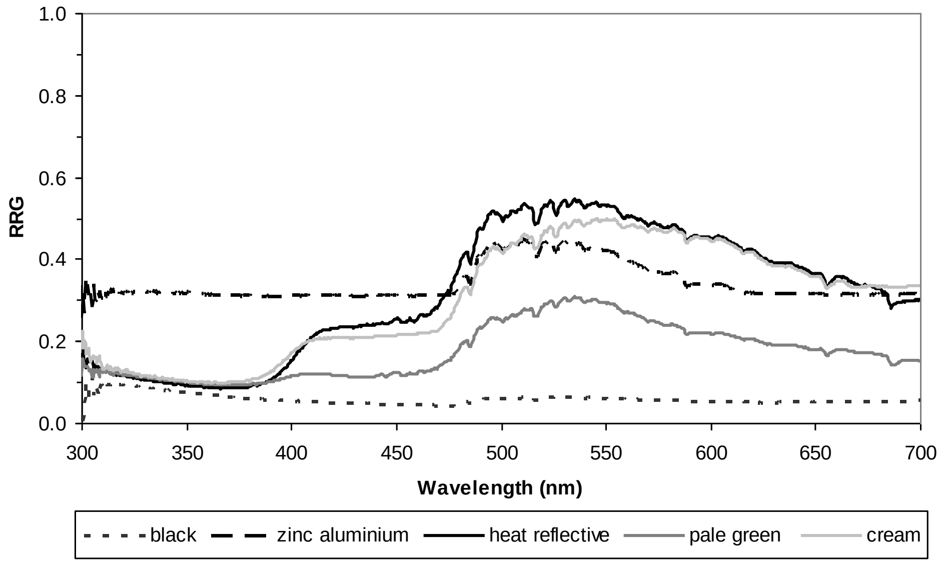
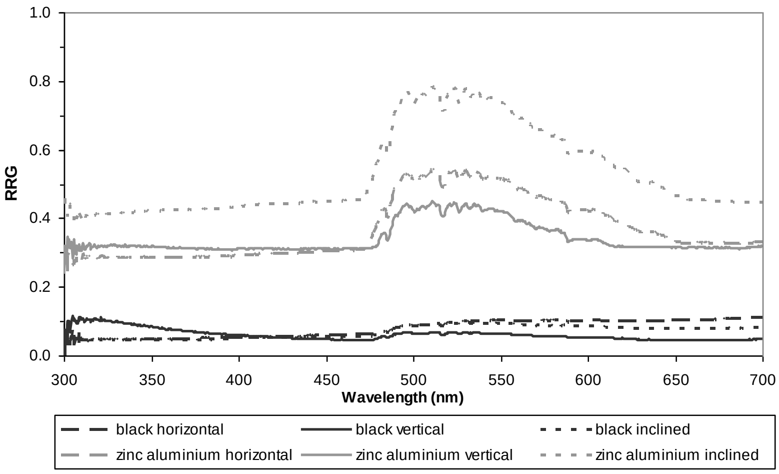


Figure 1 – Spectral RRG of various vertical trapezoidal surfaces at a SZA range of 35.5º to 47.6º.

(a)



(b)

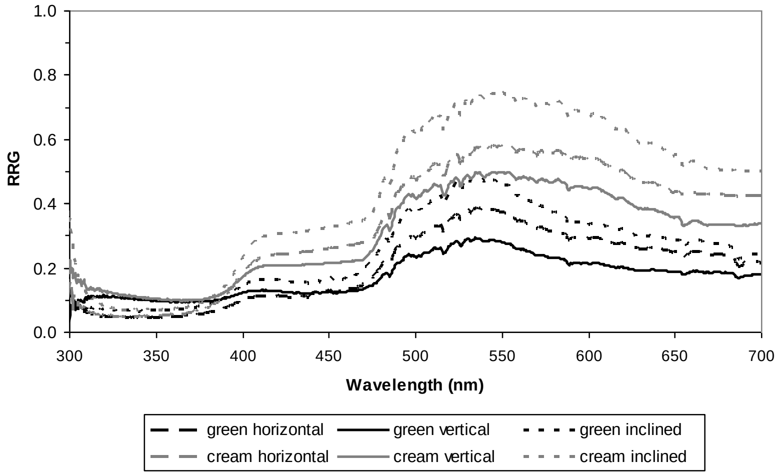
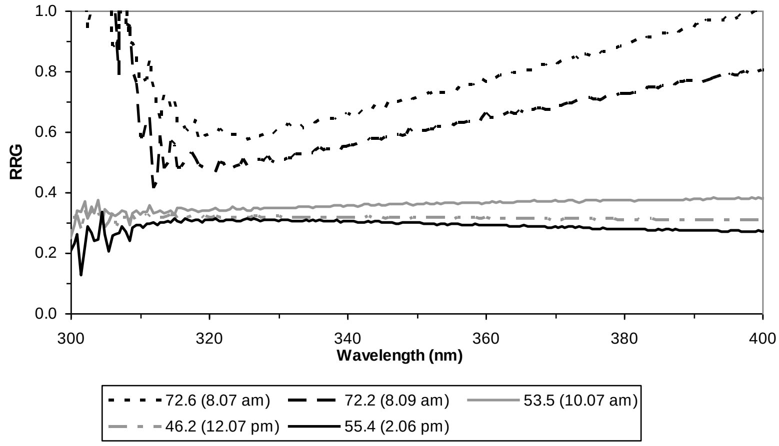


Figure 2 – (a) Spectral RRG at SZA range of 36.7º to 47.6º for horizontal, vertical and inclined surfaces for black and zinc aluminium trapezoidal metal surfaces and (b) spectral RRG at SZA range of 35.3º to 45.1º for horizontal, vertical and inclined surfaces for cream and pale green trapezoidal metal surfaces

(a)



(b)

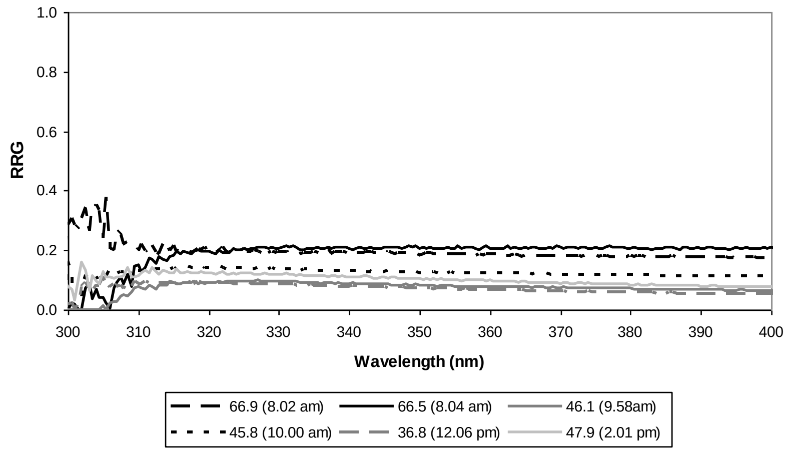


Figure 3 – (a) Spectral RRG_{UV} for varying SZAs on a north facing vertical zinc aluminium trapezoidal surface. The spectral RRG_{UV} for SZA of 55.4° is less than that of 53.5º due to the position of the sun in the west of north rather than east of north.
(b) Spectral RRG_{UV} for varying SZAs on a north facing black trapezoidal surface. The minimum RRG_{UV} is observed at 36.8º.

(a)

(b)

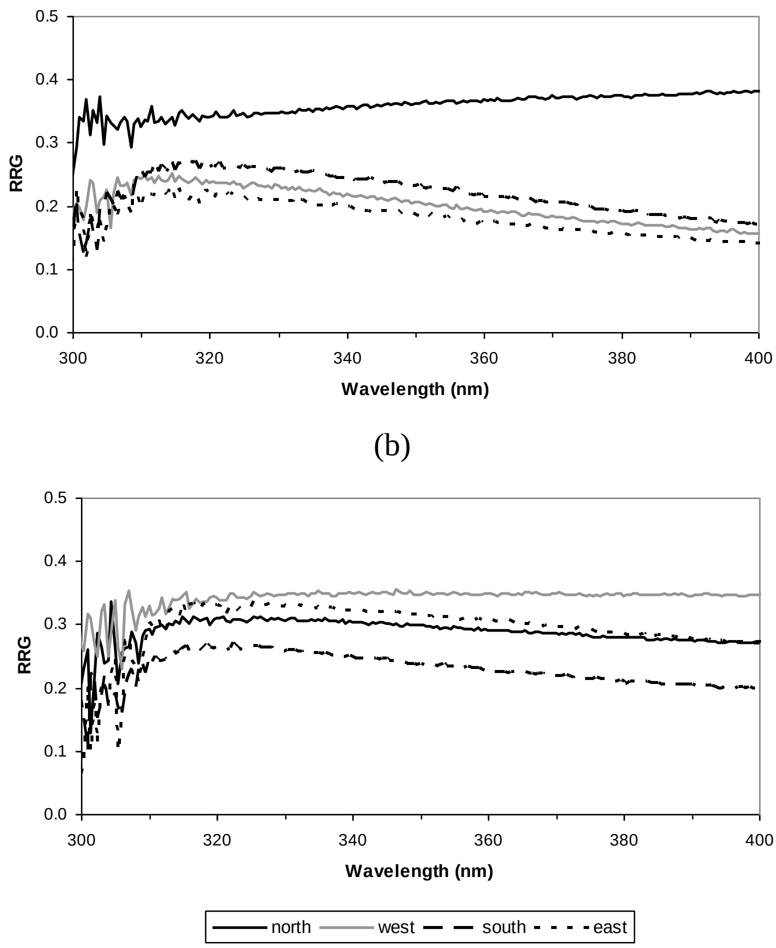


Figure 4 - (a) Spectral RRG_{UV} of vertical zinc aluminium trapezoidal surface, according to the sheet metal face orientation of north, west, south and east. The SZA range is 54º to 49º during mid-morning measurements. (b) Spectral RRG_{UV} of vertical zinc aluminium trapezoidal surface, according to the sheet metal face orientation. The SZA range is 54.9º to 61.5º during mid-afternoon measurements.

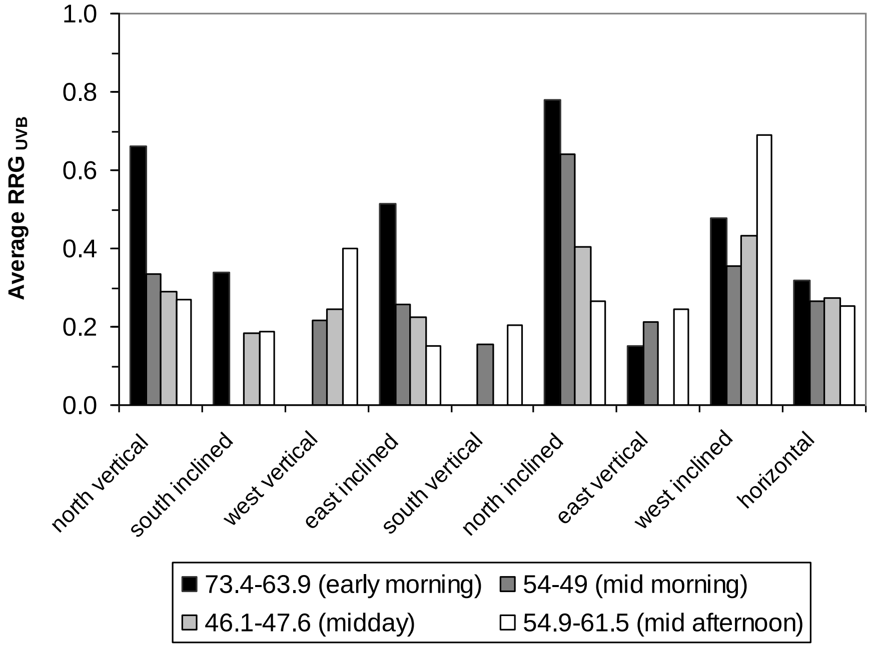


Figure 5 – Average RRG_{UVB} (from 300 nm to 320 nm) albedo for zinc aluminium trapezoidal surface at various orientations, positions and SZA.

8.2 Measuring the influence of UV reflection from vertical metal surfaces on humans

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Erythemal UV exposure for individuals involved in outside activities are affected according to surrounding structures in an urban environment. Occupational UV exposure is likely to increase by the effects of surrounding structures. UV reflections from surrounding structures, in this case vertical metal walls, were investigated for their influence on erythemal UV exposure in the southern hemisphere. Multiple dosimeters were placed at specific features on head forms, for three different vertical wall conditions, measured at hourly intervals, providing a more detailed representation of the effect of nearby (north facing) reflective wall, non-reflective wall and no wall on UV exposure for a construction worker facing the wall direction. Two types of metal sheeting walls were investigated, with the first type (shiny and smooth in appearance) showing results that indicate the UV reflectance from this surface can increase the average erythemal UV exposure by at least 20% and up to an average of 50% for certain facial positions, compared to no wall and up to 300% compared to a non reflective wall. A second metal sheeting type coated with colour, does not show as much influence on UV exposure for larger solar zenith angles compared to the first type of metal sheeting, but for smaller solar zenith angles provides an influence that approaches similar erythemal UV exposure to that when no wall is present. The time to reach the exposure limits defined by regulatory bodies for occupational UV exposure can be decreased if the first type of metal sheeting is in proximity to an outdoor worker. The experimental method of this study leads to discussion of how metal surfaces used in the construction industry physically reflect UV radiation. The conclusion is that albedo, which is traditionally used to measure UV reflection, is not an appropriate quantity to explore UV reflection from vertical metal surfaces. This may be due to the reason that metal surfaces seem to involve specular reflection as well as diffuse reflection.

1.0 Introduction

Ultraviolet (UV) radiation is an essential component of terrestrial solar radiation that is important to life on earth. In particular, UV radiation exposure in humans induces endogenous production of vitamin D_3, which is important to many body processes including bone health [1, 2]. However, at the same time, too much UV radiation is detrimental to human health, causing almost immediate effects such as erythema (sun burn) and delayed effects such as skin cancer (melanoma and non-melanoma), ocular damage, immunosuppression and DNA damage [3, 4].

To maintain the balance between under-exposure and over-exposure to UV radiation, knowledge of average UV exposure times in which maximum vitamin D_3 production and minimum skin damage (such as erythema) occurs is required. There has been recommendations made for these times [2] using models. However, these exposure times can change according to atmospheric factors as the recommended exposure times for maximising Vitamin D_3 induction and minimising damaging UV exposures by Webb et al. [2] were devised using clear sky UV irradiances in an open area and therefore suggests the need for adjustments. Atmospheric factors have been and continue to be explored [5, 6]. The exposure times should also be adjusted for localised features, such as proximity to buildings or structures. Since most of the world's population live in or near urban settings, human proximity to vertical structures is an everyday occurrence and affects humans through such factors as reflectance from solid surfaces or shading from these structures.

For outdoor workers who cannot restrict themselves to recommended time frames, preventative measures against UV radiation are recommended. For many outdoors workers, the daily UV exposure can exceed the exposure limits provided by occupational UV radiation exposure standards [7]. This was found to be true for 90% of workers in a study conducted in Australia [8] and for the majority of workers in a study conducted in alpine settings in Austria [9]. Daily exposures for the Austrian study were measured using five sensors located at different body positions. For some of the workers involved in the Austrian study, it is likely their occupation included working with metal surfaces, which are effective at reflecting UV radiation as well as visible radiation. In Australia, use of metal (coated steel) sheeting in building construction is now commonplace. Additionally, the use of including reflective surfaces on the outside of buildings to assist either heating or cooling efficiency is continually growing. The average urban dweller may be affected by increased reflectivity of surrounding vertical surfaces.

UV reflectance from natural environmental surfaces was originally measured over broadband UV irradiance, a technique employed since the early 1900s [10] and is traditionally referred to as albedo. Albedo is defined as the ratio of reflected irradiance to incident irradiance from each respective hemisphere of radiation [11], with the reflecting surface (generally accepted as) a horizontal surface, since albedo is used to measure the influence of ground surfaces on ambient UV radiation levels. Albedo is a unitless measure, either expressed as a value between 0 and 1, or as a percentage. Snow is an effective UV radiation reflector [12] and albedo will vary with the type of snow present, with albedo values ranging from 0.5 up to 1.0. Likewise, concrete covered surfaces, sand, water and many other surfaces will reflect UV radiation [13] to a lesser extent of 0.16 and below. Albedo also varies according to wavelength [14] which is important to biological processes that are wavelength specific. Albedo of metal surfaces has been investigated [13, 15] on a horizontal plane. McKenzie et al. [13] found an albedo of 0.18 for shiny corrugated iron, but Lester and Parisi [15] carried out a more extensive investigation. The surfaces in this study consisted of metallic roof sheeting in both galvanised (zinc coated stainless steel) and colour coated stainless steel sheets with albedo measurements ranging from 0.25 to 0.32 depending on wavelength for the galvanised sheeting and 0.03 to 0.12 depending on wavelength and colour for the colour sheeting. This study also considered the weighted broadband albedo with the biological effects of erythema, DNA damage, photoconjunctivitis and photokeratitis against solar zenith angle (SZA). As the SZA increases, the weighted broadband albedo at first increases, then decreases. This variation is notable, considering that albedo has generally been assumed to express reflectance for a diffusing Lambert surface [10, 13] and is therefore considered a constant value. A Lambertian surface is a surface that reflects radiation in all directions, independently of direction of irradiance incidence [16] however as Lenoble points out, no reflector satisfies Lambert's law but is a suitable approximation for most diffuse reflectors. Blumthaler and Ambach [11] carried out albedo measurements with both direct sunlight and overcast skies but found no significant difference between measurements. Specifically, this was to investigate any possible variation in the Robertson-Berger meter, but one could also take from this statement that the surfaces used to test this were diffusing Lambert surfaces, where irradiance incidence has no influence on reflection. The albedo measurements from Lester and Parisi [15] suggest a non-Lambertian surface, where irradiance incidence does have an influence on reflectance measured.

A recent study on determining if UV reflectivity differs according to horizontal, inclined or vertical planes of the reflecting surface [17] did not use albedo as the UV reflectance measurement. To compare the reflective capacity of surface position (vertical, horizontal or inclined), the authors decided that the incident irradiance would have to be consistent for any surface position. As the planes of reflected irradiance were not opposite to the hemisphere of global irradiance, albedo could not be used as the measured quantity. If albedo had been measured in the traditional sense, it could have under or over estimated measured values due to irradiance not being accounted for. This study took global UV irradiance measurements (the down-welling irradiance from the upper hemisphere of the sky) and the reflected UV irradiance from each type of surface, and referred to this as the ratio of reflected to global radiation (RRG). The study found that not only was orientation extremely important to reflectivity, but so was SZA, type of surface and position of the surface. Such variations in reflectivity that are dependent on surface characteristics, support the idea that metal surfaces are not Lambertian surfaces and therefore albedo is an inappropriate measure of UV reflection from these types of surfaces.

In the early 1900s, interests in the reflective properties of metals in the UV spectrum were already being investigated. Hulbert [18] presented a variety of metallic surfaces and their "reflecting power" in the UV spectrum. Other reasons for interest in UV reflectivity came from determining a deteriorating influence of UV radiation on paints and pigments [19] and later, an interest to see if paints could reflect UV radiation inside a building in order to bring the benefits of UV radiation and the induction of vitamin D_3 inside [20]. On the same note, metal was being used to improve lighting situations both inside and outside buildings, as a visible light reflector, but UV reflection was included in these studies [21, 22]. Additionally, interest in the use of UV reflectors to manipulate UV radiation in germicidal applications, [23] found researchers looking for reflectors with significantly high UV reflectivities, most commonly metals [24]. The use of metal in modern exterior building construction has increased considerably with little current research on their reflective capacities, as compared to the literature found early last century for different applications. This lack of current information should be improved. Consequently, this paper seeks to improve current knowledge on UV reflection from metal surfaces and determine how a vertical metal surface can or cannot influence a person's UV exposure.

2.0 Methods

Measurements of the UV exposures from reflected UV radiation were carried out at the University of Southern Queensland, (Toowoomba, Australia) in May, 2008 with the use of constructed "walls", manikin head forms, polysulphone dosimetry and a scanning spectroradiometer.

The constructed "walls" consisted of two pieces of each type of metal sheeting bolted together side by side and supported by a steel metal frame. The dimensions of the constructed "wall" were 1 m high and just under 2 m wide. Two types of metal sheeting were investigated: zinc aluminium (coated steel) trapezoidal sheeting and a pale green (coated steel) trapezoidal sheeting. The height of the trapezoidal profile between ridge and flat area was 2.9 cm, and the distance between each ridge was equally spaced at 19 cm. The ridges were aligned vertically, which is common building practice for these surface types. Each constructed "wall" faced north, as a northerly facing wall in the southern hemisphere will receive the most solar radiation during the day, provided shading does not occur.

A secondary constructed "wall" was used as a control, by placing black felt over the same type of metal sheeting to inhibit UV reflectance. The set up for this wall was the same as the reflecting wall, with the black felt attached to metal sheeting with clips to retain the ridged feature of the sheeting. The secondary control "wall" was used to determine the influence of a non-reflecting surface on a nearby person, compared to a UV reflecting surface.

The UV-reflecting and the non-UV reflecting "walls" were constructed in an open area away from any other structures. A head form was placed at 0.5 m (at the shoulder) away from each wall, with the facial features oriented towards the "wall". A third head form was placed in the open, with no nearby structures, oriented in the same manner and facing the same direction as the head forms near the constructed walls. Each head form had thirteen polysulphone dosimeters attached at specific facial or body features. These features were the top of the head, forehead, nose, chin, chest, back of head, back of the neck, cheeks, ears and shoulders.

Polysulphone, when cast in the form of a thin film, has UV sensitivity that is similar to the erythemal action spectrum [25], and for measurement of UV exposure over time can be calibrated against suitable equipment to provide a dose response. Small pieces of polysulphone are attached to a dosimeter holder with an aperture of 12 mm × 16 mm, and can be easily attached to all positions on the head form. Polysulphone personal dosimetry has been extensively documented elsewhere [26-29] so further discussion on their use in not required here, except for the calibration against a suitable spectral UV measurement device. The polysulphone dosimeters were calibrated against a scanning spectroradiometer located on a building rooftop nearby. The spectroradiometer (model DTM 300, Bentham Instruments, Reading, UK) has been running for several years and has been described previously [30]. An air conditioning unit has been added to stabilise the temperature within the environmentally sealed box to 25.0 °C ± 0.5 °C. The spectroradiometer makes both global and diffuse scans, alternating so that a global scan occurs at the 0, 10, 20, 30, 40 and 50 minute points and the diffuse scan occurs at the 5, 15, 25, 35, 45 and 55 minute points throughout the day from 5.00 am to 7.00 pm. A dose response for polysulphone dosimeters can be established by exposing a series of the dosimeters on a horizontal plane to measured solar UV exposures. A dosimeter was removed at each ten minute interval. The corresponding change in absorbance at 330 nm measured for the polysulphone dosimeter was correlated to the total UV exposure determined from the spectroradiometer measurements. Simpson's rule was used to calculate exposure over the given period of time from the global spectral measurements every ten minutes. The spectral UV data was weighted against a biologically effective action spectrum, specifically the erythemal action spectrum [25] to produce a dose response for erythemal UV exposure.

Each head form for each metal surface type was exposed from 8 am to 3 pm over two days for each surface type. Atmospheric conditions for each day of the two days of exposure per metal sheet type were very similar. Two days were required due to the lengthy set up and measurement process. The polysulphone dosimeters were replaced after each hour of exposure in order to determine if there is variation in influence to UV exposure during periods of the day. Each dosimeter was measured before and after exposure in a spectrophotometer (UV-1601, Shimadzu & Co, Kyoto, Japan) to measure the change in absorbance. The spectrophotometer has an error of ±0.004%. Finally, each dosimeter position of measured UV exposure was compared against each head form condition, to determine the influence or lack of influence of the constructed "walls" on UV exposure on each head form, for each hour of exposure. Polysulphone dosimeters have a variation in dose response calculation of about 10% [26] up to a change in absorbance of 0.3. As the maximum for a dosimeter in this study does not exceed this change in absorbance, the error in the calculated erythemal exposure for each dosimeter is 10 %. For the relative measurements, the error can accumulate to approximately 20 %. This error should take into account any minor changes in the spectrum.

3.0 Results

Figure 1 demonstrates the head forms used to conduct this preliminary investigation. Of the three head forms, two are in proximity to "walls" and one is placed in an open area. The head form in figure 1 (b) is near the UV reflecting wall (zinc aluminium trapezoidal sheeting) and the head form in figure 1 (c) is near the non-UV reflecting wall. In figure 1 (b) the face is illuminated by the reflected visible radiation, reducing shadow, which is defined on the face in figure 1 (c). All three photographs were taken at the same time in the morning on the same day. Figure 1 (a) is the head form placed in an open area. This head form has been photographed from the front to display dosimeter positions, rather than from the side, and faces the same way as the head forms near constructed walls. The shadow on the face is due to the sun's position behind the head form.

3.1 Zinc aluminium trapezoidal sheeting

For each surface type of the zinc aluminium trapezoidal sheeting and the pale green coated trapezoidal sheeting, a full day of data was collected for each dosimeter position, on each head form, for each condition of exposure. The data for each head form was then averaged over all the dosimeter positions to compare erythemal UV exposure for each exposure condition. Figure 2 (a) and 3 (a) show the average erythemal UV exposure per dosimeter position for each head form and related exposure condition for each hourly period. For zinc aluminium trapezoidal sheeting (Figure 2 (a)), the average erythemal UV exposures show that early morning to mid afternoon erythemal UV exposures range from 0.5 SED to 2.5 SED per hour. One SED is equivalent to 100 J/m^2 [31] and for a person with type 1 or type 2 skin, one MED (minimum erythemal dose) can range from 2 to 3 SED. An outdoor worker who is in proximity to zinc aluminium sheeting could easily exceed the exposure limits as given in *Occupational exposure to ultraviolet radiation* [7], and even importantly, could achieve the exposure limits in less time than is standard for an open area. The zinc aluminium trapezoidal surface (Figure 2a) shows that for each hour of exposure the head form near the UV reflecting wall is receiving on average higher erythemal UV exposure than the head form that is not near a wall. Figure 2 (b) shows the erythemal UV exposure averaged over all the dosimeter positions accumulated over the day. This figure shows that the accumulated erythemal UV exposure for the zinc aluminium trapezoidal surface is higher than for the head form near no wall.

The erythemal UV exposure recorded for the head form near the non-reflecting UV surface, in all hourly cases, is less than the erythemal UV exposure recorded for the head form in the open. The non-reflecting wall data therefore shows that the presence of a non-reflective wall can block diffuse UV radiation. Both non-UV reflecting and UV reflecting surfaces will presumably block some of the diffuse UV radiation from an individual near a wall, however the UV reflecting wall in this case appears to reflect more UV radiation than it blocks.

To confirm that the zinc aluminium trapezoidal wall reflects more UV radiation than it blocks, the ratio of the erythemal UV exposure averaged over all the dosimeter positions per head form condition was investigated for decreasing head form area. Figure 2 (a) represents the average erythemal UV exposure per dosimeter position on each head form per hour. Table 1 expresses this data in terms of ratios, specifically the conditions of: ratio of the reflective wall UV exposure to no wall UV exposure, the ratio of the reflective wall UV exposure to the non-reflective wall UV exposure and the ratio of the non-reflective wall UV exposure to no wall UV exposure. The ratios are provided for the conditions of the erythemal UV exposures averaged over all dosimeter positions, the average erythemal UV exposure of the positions on the face, chest and ears and the average of the erythemal UV exposures to the facial positions. By considering the ratios of the exposures for these three conditions, the data is more focused on those head form features which are more dependent on reflected UV radiation than direct UV radiation. At first, it was thought the deduction of certain data values from the averages would not change the ratios as these positions would generally be equivalent in erythemal UV exposure for all conditions as they are not oriented towards a wall (if there was one present). However, deduction of these data values actually increased the ratios if the zinc aluminium wall was part of the condition. This suggested that the erythemal UV exposures at those dosimeter positions were hiding some of the effect of the dosimeter positions that were oriented towards a wall. To confirm this was true, further features were deducted so that only the facial features that are oriented towards a wall were averaged (forehead, nose, chin, cheeks). This again showed an increase in ratios if the reflective wall for zinc aluminium trapezoidal was involved. The daily average in Table 1 shows this increase, as the number of dosimeter sites used in the average is reduced. This table shows that UV irradiance reflected from a UV reflective vertical surface (specifically zinc aluminium trapezoidal sheeting) can affect specific body positions by increasing erythemal UV exposure by an average of at least 20 % and up to 50 % compared to having no vertical surface nearby at all. In comparison to a non-reflective wall, erythemal UV exposure received near a reflective wall of zinc aluminium trapezoidal sheeting, can increase average UV exposure by a minimum of 40% and up to 300% when specifically considering facial features.

3.2 Pale green trapezoidal sheeting

Pale green trapezoidal sheeting does not display the same type of erythemal UV exposure influence. Figure 3 (a) shows that for only during the hour before midday, UV exposure increased due to the proximity of pale green trapezoidal sheeting as compared to no wall at all. The rest of the day indicates that the influence of the UV reflecting wall is less than that for the head form near no wall, or sometimes equivalent to the influence due to the non-UV reflecting wall. The hour before midday showing increased erythemal UV exposure for the head form near the reflective wall compared to a head form near no wall, is also influential to the next hour of exposure when considering the accumulated UV exposures since 8 am in Figure 3 (b).
For some times of the day when the non-reflective and reflective erythemal UV exposures on the head forms are equivalent, the UV reflection from the pale green trapezoidal surface appears to be minimal. This effect may be attributed to the relative proportions of direct and diffuse UV radiation. In the morning at larger SZA, the proportion of diffuse UV to direct UV is large. Around noon, this proportion decreases as the SZA of the sun decreases. If both walls block diffuse UV radiation and the reflective wall is only reflecting minimal UV at larger SZA, then the conclusion from this effect would be to assume that diffuse UV radiation does not reflect effectively from this type of surface and therefore has little influence on the head form at the large SZA. For the times of the day when the reflective wall erythemal UV exposures exceed the erythemal UV exposures from the non-reflective wall, the relative proportion of diffuse UV is less and the influence of the reflective wall is higher with increased direct UV. For the hour before midday, where exposure near a reflective wall is more than exposure near no wall, the proportion of diffuse to direct UV must be small enough that direct UV is highly influential. This could indicate that at certain SZA, pale green trapezoidal sheeting could be highly reflective to UV radiation. However, by reducing the number of dosimeters considered, calculating the average and considering the ratio of UV exposures as described earlier for zinc aluminium trapezoidal surfaces, Table 1 shows the influence, or rather,the lack of influence on erythemal UV exposures on the head form near the reflective wall is apparent in Table 1.
For the average erythemal UV exposure for all dosimeter positions for pale green trapezoidal sheeting, it appears that the erythemal UV exposure is on a similar value to the head form near no wall. This at first suggests that the diffuse UV radiation blocked by the wall is replaced by the reflected UV radiation. However, as features such as the top of head, back of neck, back of head and shoulders are deducted from the averages, it is shown that these values were increasing the average erythemal UV exposure influence per dosimeter per head form. When only the face, chest and ears are considered, the erythemal UV exposure experienced by the head form near the reflective wall is only 70% of that experienced by the head form with no wall nearby, and changes very little when only the facial features are considered. It is possible that the change from large values to low values from the average of all features to just facial features may have occurred due to an outlier in the original data. This conclusion may be supported by the unusual value for the all features averaged for the non-reflective to no wall ratio, which at 1.2 stands out as unlikely for a non-reflective wall. However, when some of the body positions are deducted from this average, the value drops below one, which is as expected from a non-reflective wall. Despite the lower ratios for the pale green sheeting, this does not suggest that no UV reflection occurs from the pale green trapezoidal sheeting, as can be seen when considering the ratios calculated for the non-reflective wall to no wall for the same day of exposure as the pale green trapezoidal. Presence of thea non–reflective wall can block up to an average of 50 % UV radiation from facial

features, which is shown to be consistent for each day of measurement when measuring different reflective wall types (in Table 1). The data suggests there is still UV radiation reflected from the pale green trapezoidal sheeting, just not in the same capacity or quantity as from the zinc aluminium sheeting. Taking the earlier discussion of direct and diffuse UV proportions, Table 1 helps to show that while the hour before midday is not as influential at increasing UV exposure as first thought, it is can still be influential, by maintaining an erythemal UV exposure that is very similar to having no wall at all. A non-reflective wall may block up to fifty percent of diffuse UV radiation at this time, but the pale green surface is reflecting some radiation, almost enough to make up for the blocked diffuse radiation. This is confirmed by the ratio of the erythemal UV exposure from the reflective wall to the erythemal UV exposure from the non-reflective wall, which shows that the pale green trapezoidal sheeting can increase average UV exposure compared to the non-reflective wall by a minimum of 10% and up to 30% for facial features.

4.0 Discussion

4.1 Overall influence of metal sheeting walls

The data in this study indicates that when standing, working or sitting in the presence of a nearby metal surface similar to the sheeting types used in this study, that the erythemal UV exposures received by features that are facing the wall are the most likely to be influenced by UV reflection from the wall. Figure 4 shows the average daily ratios of dosimeter positions, and highlights the erythemal UV exposures received by forehead, nose, chin and chest as the most significantly influenced by the zinc aluminium sheeting. By considering each dosimeter position separately over a day, the body features such as shoulders and ears that do not necessarily face the wall can still have UV exposures influenced by a reflective surface like zinc aluminium trapezoidal sheeting.

4.2 UV reflection

The discussion of pale green trapezoidal sheeting reflecting more when higher proportions of direct UV are present can also be applied to zinc aluminium trapezoidal sheeting. In the case of zinc aluminium trapezoidal sheeting, we can see from Figure 2 (a), that erythemal UV exposures experienced by the head form near the zinc aluminium, are lower in the mornings and afternoons than at midday. This reinforces the idea that the lower the proportion of diffuse UV to direct UV, the greater the influence of a metal surface. So direct UV is more effectively reflected than diffuse UV, but the zinc aluminium trapezoidal sheeting reflects both direct and diffuse UV more effectively than the pale green trapezoidal sheeting, and therefore is more influential on the erythemal UV exposures a person might experience.

4.3 Variability in UV reflection

There is an anomaly to this conclusion, and it is visible in Figure 2 (a) over the hour of exposure from 1 pm to 2 pm. Prior to the data collected in this paper, a few trial runs of the experimental procedure were carried out using zinc aluminium trapezoidal sheeting. In these trial runs, this anomaly was observed for the same time period, and only this time period. The suggested cause for this observation is due to the azimuth of the sun, at which there might be some point in the afternoon where both the azimuth and solar zenith angles of the sun decrease the proportion of direct UV to diffuse UV for that particular wall orientation. As this does not occur for the hour of exposure after 1 pm to 2 pm, then it remains to be seen from further experimental work in seasons other than autumn and for other wall orientations, if this hypothesis is true.

4.4 Why does the UV reflection change?

The behaviour of the reflective capacity of these metal surfaces also induces interest into how UV is reflected from these particular metal surfaces and whether the trapezoidal shape of the metal sheeting is important to the reflective capacity. However, any affect of the trapezoidal shape will depend on reflective behaviour.

There are two types of reflective behaviours, diffuse and specular reflection. Diffuse reflection is not to be confused with diffuse radiation. Diffuse reflection occurs when incident radiation penetrates the surface, and is then backscattered by the surface molecules 16. This type of reflection occurs due to the previously mentioned Lambert surface, which reflects radiation in all directions regardless of the angle of incident radiation. Specular reflection occurs at the interface of the surface, reflecting radiation in specific directions and depends on the angle of incident radiation 16. While there is no such thing as a perfectly diffusing surface (also called a Lambert surface), there is also no such thing as a perfectly specular surface, although mirrors may be considered close approximations. The behaviour of the reflected UV irradiance measured from the metal surfaces in this study, given the data collected in previous studies 15, 17 suggests that the metal surfaces are either specular reflecting surfaces or a combination of both specular and diffuse reflecting surfaces. The possibility of either is dependent on whether the metal surfaces could be classified as smooth or rough. By visible inspection, the surfaces appear smooth apart from the ridges, but it is also at athe molecular level that isis also important to reflection. If these surfaces werecould be considered rough at the molecular level, specular reflection will produce uneven back scattered reflection (as the angle of incidence changes as the surface molecule inclination changes) producing reflection that may appear to be diffuse. Alternatively, smooth surfaces could produce either specular or diffuse reflection, depending on the surface type. Research on this idea has been carried out 32 in other fields of study, but is not sufficient at present, to be able to define the particular reflecting behaviour of these metal surfaces. This would be an interesting study to pursue to better understand reflection of UV from metal surfaces in urban environments.

5.0 Conclusions

This study has extended and improved on previous work carried out to determine erythemal UV exposure for workers in the construction industry. Previous studies9 used a small number of dosimeters to estimate erythemal UV exposure over a day, without distinguishing between the proximity of workers near surrounding structures and those who are not. The use of multiple dosimeters placed at specific features on a head form, for three different vertical wall conditions, measured at hourly intervals, has provided a full more detailed representation of the effect of nearby (north facing) reflective, non-reflective and no walls on UV exposure for a construction worker facing the wall.

The data collected in this study has shown that vertical metal surfaces can be influential in to the erythemal UV exposure received by a person when in proximity to such a surface. In comparison to a person in an open area, shiny smooth surfaces (zinc aluminium trapezoidal sheeting) can increase erythemal UV exposures by an average of 20 %, and up to 50 % for a person’s face when positioned at an arm’s length from that type of vertical surface. When compared to a person’s erythemal UV exposure near a non-reflective wall, the same type of reflective wall increases UV exposure by up to 300% for facial features. For colour coated surfaces such as pale green trapezoidal sheeting, the influence is not nearly as great as that of the zinc aluminium trapezoidal sheeting, but at a certain time of the day, this type of wall can influence erythemal UV exposures by reflecting almost as much UV radiation as it blocks.

This study has also highlighted some different ways of how UV reflection is measured and recorded. In particular, this study indicates that the traditional method of using the quantity of albedo is not sufficient to measure UV reflection from metal surfaces. Given that it is very likely that metal is a specularly reflecting surface, and that metal is used in construction at various orientations (vertical and inclined as well as horizontal), other techniques to measure UV reflectance from metal surfaces should be utilised, such as that by Turner et al. 17.

In general, these types of surfaces need to be taken into consideration when a person may want to estimate erythemal UV exposure. The most common example of a person wishing to do this would be a person working in the construction industry, although every person should be made aware of these types of metal surfaces and its influence over UV radiation, and take appropriate precautions. Urban dwellers may have their personal erythemal UV exposure regularly influenced by the presence of nearby vertical surfaces.

Lastly, the data collected in this study will contribute to the overall knowledge of UV radiation and how it interacts within the terrestrial atmosphere. Further work is planned on extending this knowledge for other seasons and surface orientations, as well as different surface types.

6.0 References

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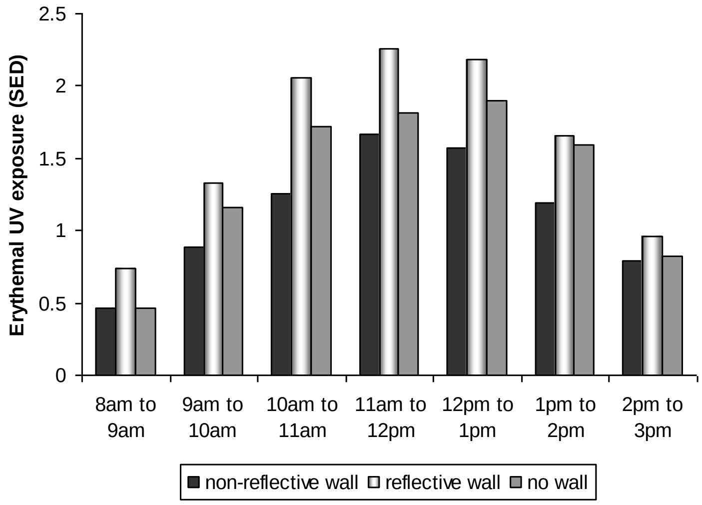
Figures

Figure 1- (a)Above - Head form with attached polysulphone dosimeters placed in the open (b) Top right - head form with attached dosimeters placed near a reflecting wall (c) Bottom right - head form with attached dosimeters placed near a non-reflecting wall

(a)



(b)

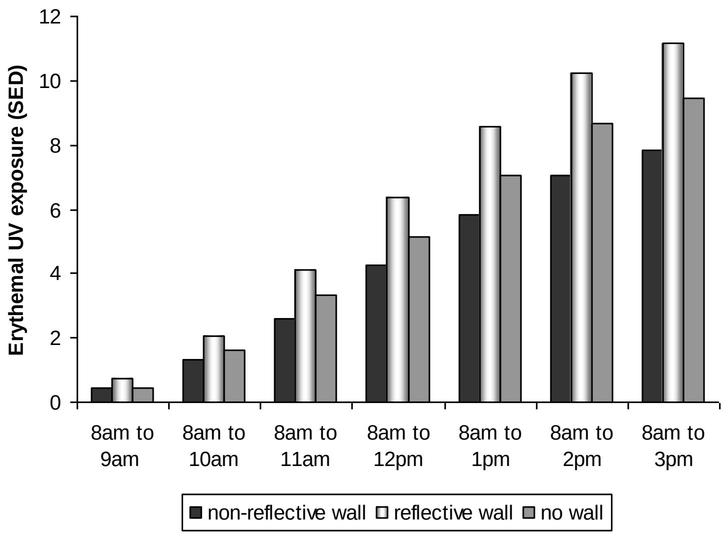
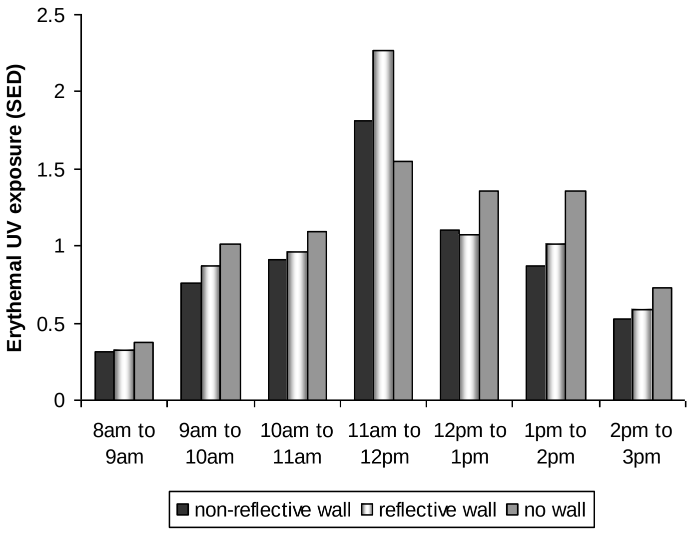


Figure 2 (a) – Exposures averaged over all the dosimeter positions for each hour of exposure for each head form for zinc aluminium trapezoidal sheeting. (b) Accumulated UV exposure averaged over all dosimeter positions for each head form for zinc aluminium trapezoidal sheeting.

(a)



(b)

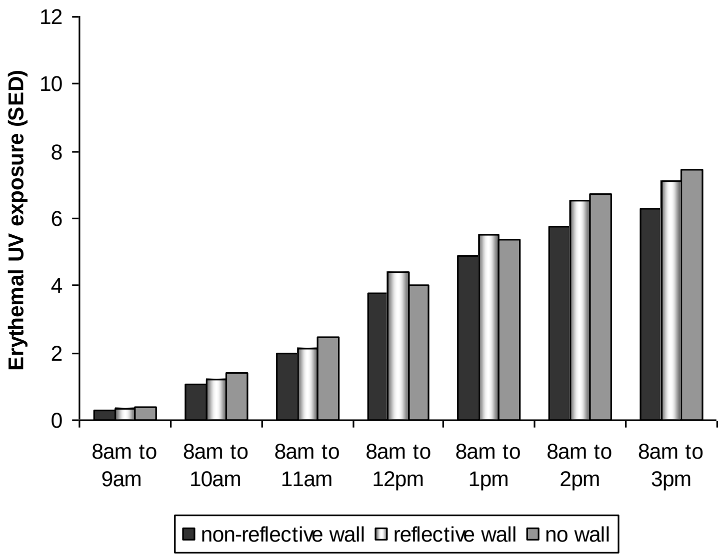


Figure 3 – (a) Exposures averaged over all the dosimeter positions for each hour of exposure for each head form for pale green trapezoidal sheeting. (b) Accumulated UV exposure averaged over all dosimeter positions for each head form for pale green trapezoidal sheeting.

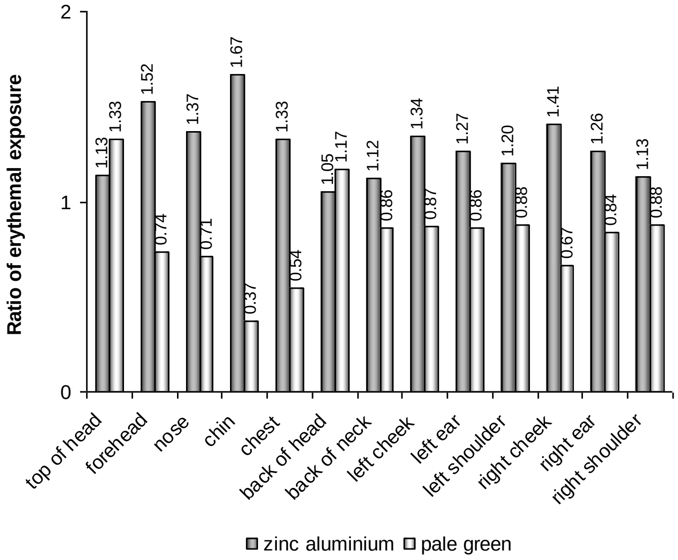


Figure 4 – Ratio of the erythemal exposure received by the head form near the UV reflecting wall to the head form with no wall, for each dosimeter position, averaged over the entire exposure period for zinc aluminium trapezoidal sheeting and pale green coated trapezoidal sheeting.

Table 1 – The hourly erythemal UV exposure as a ratio of the reflective wall to no wall case, the reflective wall to non-reflective wall case and the non-reflective wall to no wall case. The exposures are averaged over all the dosimeter positions, averaged over the face, chest and ear positions and averaged over the facial features only, for both metal sheeting types: zinc aluminium trapezoidal and pale green trapezoidal.

	8am to 9am	9am to 10am	10am to 11am	11am to 12pm	12pm to 1pm	1pm to 2pm	2pm to 3pm	Daily average
Zinc Aluminium trapezoidal								
All features average								
Reflective to no wall	1.6	1.1	1.2	1.2	1.2	1.0	1.2	1.2
Reflective to non-reflective	1.6	1.5	1.7	1.4	1.4	1.4	1.2	1.4
Non-reflective to no wall	1.0	0.8	0.7	0.9	0.8	0.8	1.0	0.9
Face+ chest + ears average								
Reflective to no wall	1.9	1.9	1.5	1.6	1.4	1.0	1.3	1.4
Reflective to non-reflective	2.3	2.9	3.9	3.3	2.8	1.8	2.2	2.7
Non-reflective to no wall	0.8	0.5	0.4	0.5	0.5	0.6	0.6	0.6
Facial features (only) average								
Reflective to no wall	1.8	1.4	1.5	1.7	1.5	1.0	1.5	1.5
Reflective to non-reflective	2.9	3.2	4.2	3.7	3.3	1.9	2.8	3.1
Non-reflective to no wall	0.6	0.5	0.4	0.5	0.5	0.5	0.6	0.5
Pale green trapezoidal								
All features average								
Reflective to no wall	0.9	0.9	0.9	1.5	0.8	0.8	0.8	0.9
Reflective to non-reflective	1.0	1.2	1.0	1.3	1.0	1.2	1.1	1.1
Non-reflective to no wall	0.8	0.8	0.8	1.2	0.8	0.6	0.7	0.8
Face + chest + ears average								
Reflective to no wall	0.6	0.6	0.6	0.9	0.6	0.9	0.7	0.7
Reflective to non-reflective	1.1	1.2	1.3	1.4	1.1	1.4	1.2	1.2
Non-reflective to no wall	0.6	0.5	0.4	0.7	0.6	0.6	0.6	0.6
Facial features (only) average								
Reflective to no wall	0.6	0.6	0.6	1.0	0.6	0.9	0.7	0.7
Reflective to non-reflective	1.2	1.2	1.5	1.5	1.1	1.6	1.2	1.3
Non-reflective to no wall	0.5	0.5	0.4	0.6	0.5	0.5	0.6	0.5