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

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Abstract

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.

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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.

Methodology

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.

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.

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 more 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.

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 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, the lack of influence on erythemal UV exposure 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 the 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 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.

Discussion

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 exposure 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.

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 exposure 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 exposure a person might experience.

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.

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 behaviour, 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 the molecular level that is important to reflection. If these surfaces were 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.

Conclusions

This study has extended and improved on previous work carried out to determine erythemal UV exposure for workers in the construction industry. Previous studies[9] 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 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 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 exposure 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 exposure 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.

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List of Figures

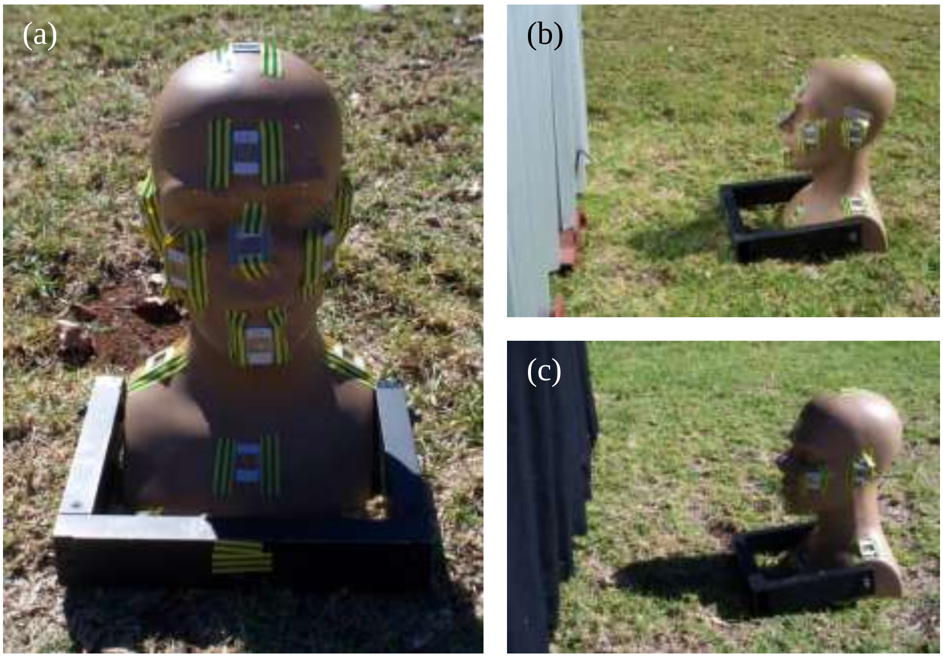
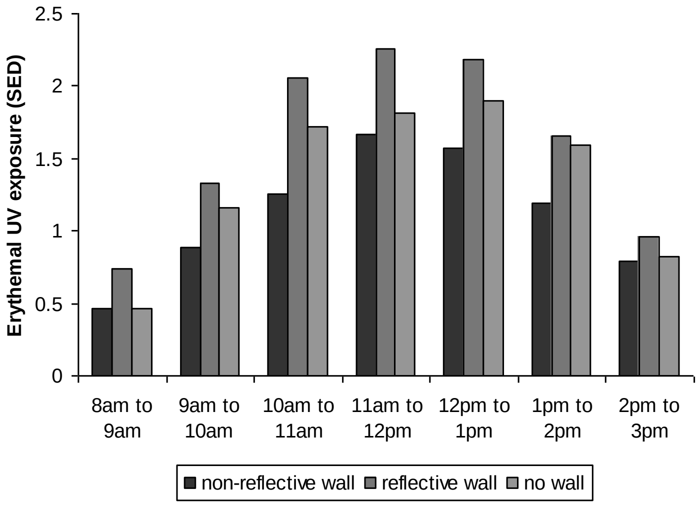


Figure 1- (a) Head form with attached polysulphone dosimeters placed in the open (b) head form with attached dosimeters placed near a reflecting wall (c) head form with attached dosimeters placed near a non-reflecting wall.

(a)



(b)

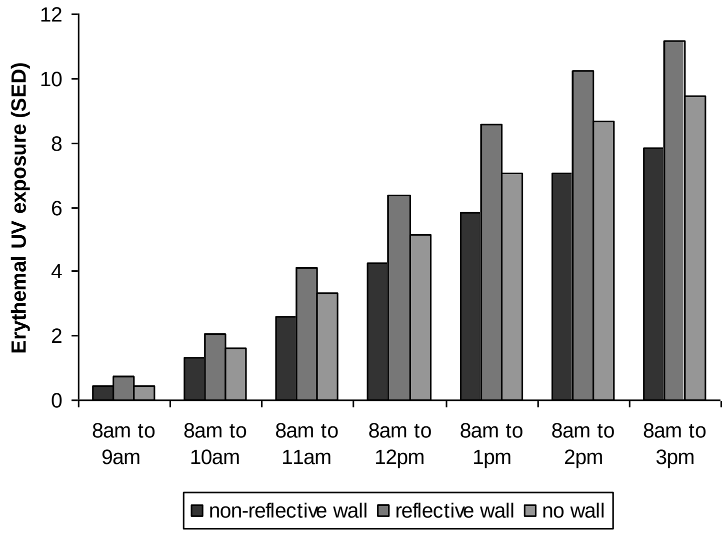
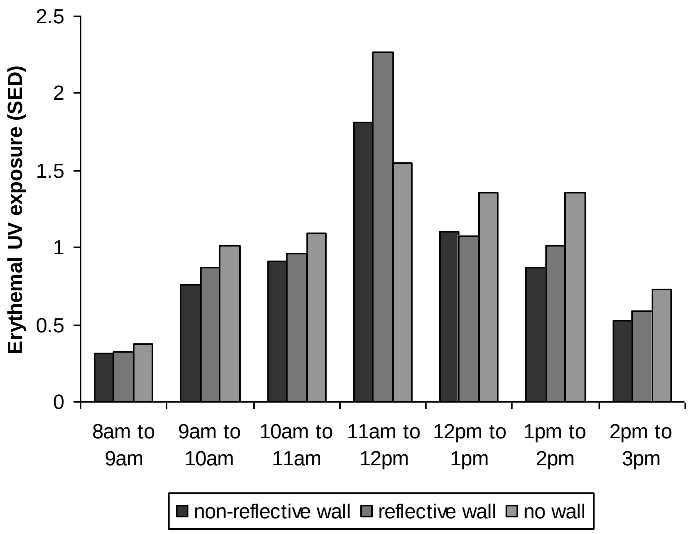


Figure 2 (a) – Exposures averaged over all the dosimeter positions for each hour of exposure for each head form for zinc aluminium trapezoidal sheeting. (b) Accumulated UV exposure averaged over all dosimeter positions for each head form for zinc aluminium trapezoidal sheeting.

(a)



(b)

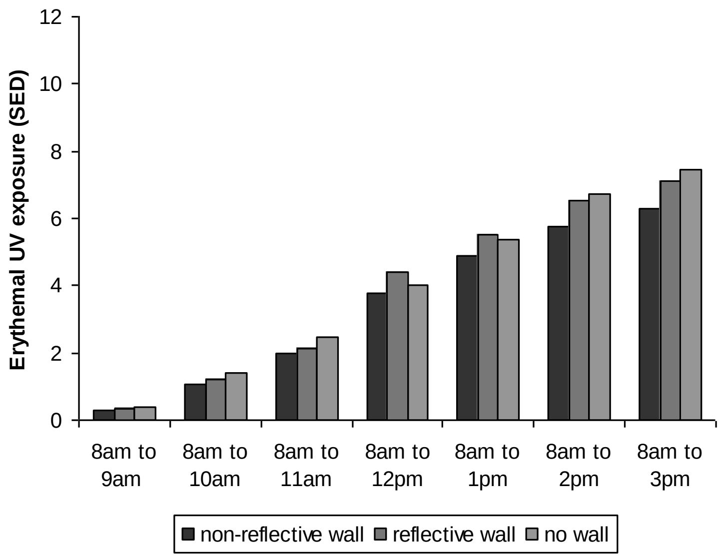


Figure 3 – (a) Exposures averaged over all the dosimeter positions for each hour of exposure for each head form for pale green trapezoidal sheeting. (b) Accumulated UV exposure averaged over all dosimeter positions for each head form for pale green trapezoidal sheeting.

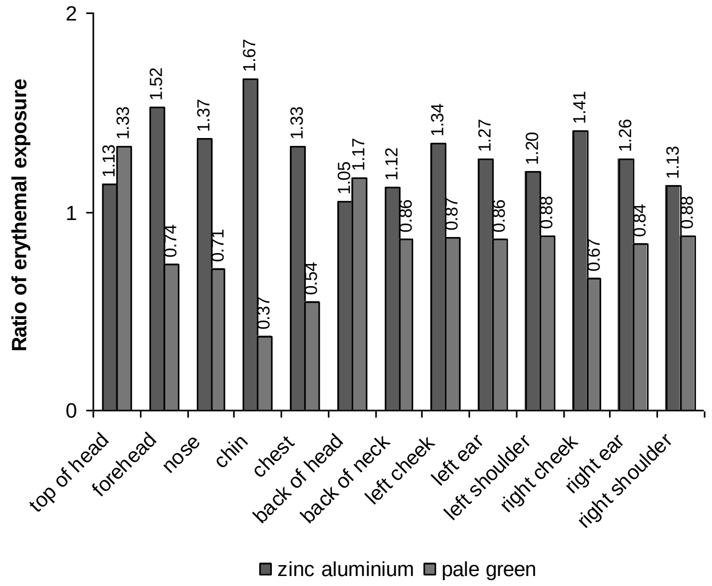


Figure 4 – Ratio of the erythemal exposure received by the head form near the UV reflecting wall to the head form with no wall, for each dosimeter position, averaged over the entire exposure period for zinc aluminium trapezoidal sheeting and pale green coated trapezoidal sheeting.

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	0.9	0.9
Face+ chest + ears average								
Reflective to no wall	1.9	1.4	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