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Influence of reflected UV irradiance on occupational exposure from combinations of reflective wall surfaces

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Outdoor workers who occupationally spend large periods of time exposed to ultraviolet irradiance are at increased risk of developing certain types of non-melanoma skin cancer in addition to being prone to erythema and eye damage. UV exposure to workers is affected by a number of factors including geographic location, season, individual biological factors and the local surroundings. Urban environments can provide surrounds that contain surfaces that reflect UV radiation which can enhance UV exposure to construction workers, in both the vertical as well as horizontal plane. However it was unknown how different constructed configurations of the surfaces may additionally influence UV exposure for a worker, such as corners opposed to walls. This study shows that for highly UV reflective surfaces the influence on erythemal UV exposure is approximately the same regardless of constructive type, but there is statistically significant difference observed for lower UV reflecting surfaces in conjunction with constructive type. This is comparable to influence of body site on relative UV exposure, and together may provide a method that may assist in reduction in UV exposures. Regression analysis provides a more effective means to determine a UV reflective factor for a surface type, than previously used averaging methods. Additionally, this knowledge may be used by workers, workplaces and advisory bodies to assist with developing further protective strategies that aim to provide more moderate UV exposures to outdoor workers.

Introduction

Solar ultraviolet (UV) radiation is known to be beneficial to humans in moderate quantities through vitamin D_3 production.[1–4] Conversely it can be detrimental in excessive quantities through an increased induction of erythema (sunburn), non-melanoma and melanoma skin cancer, ocular damage, DNA damage[5] and is linked to immunosuppression and photo aging.[6] Populations of UV sensitive people are generally at risk from damage due to UV radiation when living in areas of high ambient UV radiation, however that risk is increased in members of the population who occupationally spend working hours exposed to solar UV radiation[7–9] depending on skin type and individual factors.[10] It has previously been shown that outdoor workers can be exposed to excessive levels of UV exposure, and that UV exposure is dependent on the occupation.[8,11] Studies also show that most outdoor workers often exceed occupational recommended UV exposure levels.[11–13] Recommendations for occupational UV exposure levels are readily available.[14,15] UV exposure to outdoor workers can be managed; however factors that affect UV exposure need to be assessed in order to determine appropriate recommendations to outdoor workers.[16] Positive association has been found between development of squamous cell carcinoma (SCC) and occupational exposure[7,17–19] with a relative risk factor compared to personal sun exposure by an individual of 1.64[7] as calculated from data from a previous study by Elwood and Jopson.[20] However Diepgen and Mahler[17] find this relative risk higher than two. History of sunburn is also linked to risk of developing non-melanoma skin cancer and melanoma along with many other variables.[18] For some occupational workers, UV reflection is an additional contributor to solar exposure by affecting normally shaded parts of the body through posture or otherwise[19] such as construction workers who may deal with UV radiation reflecting surfaces. Such local factors can be just as important to understand individual UV exposures of workers as well as environmental factors.[13] Increased UV exposure to the body has been shown to occur for specific types of man-made surfaces in urban settings.[21] However the urban setting is not just made of single walls, but combinations of walls (for example, corners). This study will determine if a worker located within a combination of two walls (a "corner") with full solar UV exposure will be exposed in different quantities than a worker located near an unbroken flat wall of the same material, and if so, what that impact will mean to the worker's UV exposure.

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Methodology

The measurements for this study were carried out at sub-tropical latitudes at the University of Southern Queensland, Toowoomba, Australia (27.5°S, 151.9°E). Data were obtained by constructing "walls" and "corners" combined with the use of polysulphone dosimetry and manikin head forms. Data for the walls from a previous study[21] obtained in May 2008 in Autumn, were compared to data for the corners which were collected during Autumn 2009 (over five days in March and April for both surface corner types). Details of the constructed walls are found elsewhere.[21] The corners were constructed using the same materials as the walls, using two types of standard building materials (in Australia): zinc aluminium coated steel and pale green painted coated steel with a trapezoidal profile. Corners were made with two sheets of each metal type of size 90 cm × 100 cm at right angles to each other (Fig. 1). The height of the ridges in the sheeting is 2.9 cm (depth) and the ridges are equally spaced at 19 cm. The ridges were aligned vertically, in keeping with standard building practises. Each corner was oriented with one wall facing north, and the other east (north-east) until noon, and changed to face north and west (north-west) after noon for maximum direct solar UV radiation and to reduce the influence of shading. Manikin head forms were placed at a distance of 0.5 m from each panel. The face was oriented towards the north facing panel for both the morning and the afternoon measurement sessions. At the same time, a second manikin head form was located in the same area with no vertical surfaces nearby. This manikin head form provides control exposures without the influence of nearby vertical structures. A third manikin head form was placed in front of the same style of structure as the first manikin head form, constructed instead with a non-UV reflecting surface. The data obtained from this head form were to compare the effect of sky view blocking of the structure. This was the same strategy used in the wall study.[21]

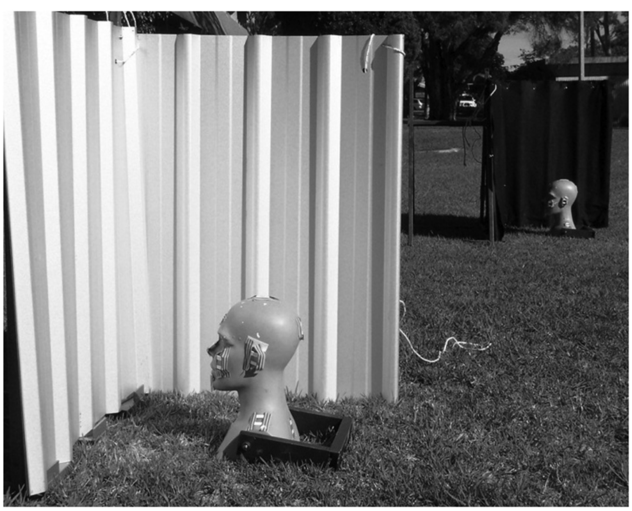

Fig. 1 Manikin head forms positioned near a UV reflective corner and a non-reflective corner.

Each manikin head form had thirteen polysulphone dosimeters attached in the same position on each manikin. These positions were vertex, forehead, nose, chin, chest, both cheeks, both ears, back of head, back of neck, and both shoulders (Fig. 1). Dosimeters were replaced hourly to determine a breakdown in the daily UV exposure, from 8 am to 3 pm (wall) or 8 am to 4 pm (corner). Previous published studies have shown that time of day and season are important to the reflective capacity of the surface types investigated.[22,23] The atmospheric conditions for the wall data as reported in Turner and Parisi[21] was clear with low to no clouds. The ozone was 255–259 DU (zinc aluminium) and 252–275 DU (pale green) as provided by the U.S. National Aeronautics and Space Administration's Ozone Monitoring Instrument.[24] The atmospheric conditions for the corner data included cloud cover that did not go above 40% of the total sky in the afternoon with less cloud in the morning (zinc aluminium) and clouds that did not exceed 20% total sky (pale green). The ozone ranged from 255 DU to 266 DU over the days of measurement for the zinc aluminium surface.[24] The ozone is not available for the days the pale green corner was measured.

Polysulphone dosimetry is an acceptable method of approximating personal erythemal UV exposures on humans[25,26] with a response that approximates the erythemal action spectrum[27,28] and therefore providing a biologically effective response.[29] The use of the erythemal action spectrum to estimate appropriate UV exposure is based on the premise that history of sunburn is strongly linked to all types of skin cancer.[18] Polysulphone is a photoreactive material that changes optical density when exposed to UV radiation. Polysulphone is cast in thin film of approximately 40 μm and mounted in plastic holders with apertures of 16 mm × 12 mm. The dosimeters are calibrated against a scanning spectroradiometer that is located on a building rooftop close to the measurement site. The spectroradiometer (model DTM 300, Bentham Instruments, Reading, UK) has double grating monochromators with 2400 lines per mm blazed at 250 nm with a 600 mm focal length. The spectroradiometer is sealed within a temperature controlled container at 25 °C. The specifics of the spectroradiometer have been described previously.[30] The spectroradiometer makes global scans every ten minutes from 5.00 am to 7.00 pm every day. The change in optical density of the dosimeters is determined by measuring the absorbance of each dosimeter pre and post exposure using a spectrophotometer (UV-1601, Shimadzu & Co, Kyoto, Japan) with an error of ±0.004%. Polysulphone dosimeters have a variation in dose response of 10% for changes in absorbance up to 0.3.[25] No dosimeter in this study exceeded 0.3 absorbance therefore the error of the dosimeters is taken as ±10%. The dosimeters did not exceed this absorbance level due to the dosimeters being replaced after each hour of exposure. Exposure ratios calculated from the dosimeters have an error of ±20%.

Data obtained from the manikin head forms that were located near a reflective surface (influenced erythemal exposure) were compared to the data obtained from the manikin head form not located near any surface (control erythemal exposure). The data were analysed in Microsoft Excel 2010 using the Data Analysis package, by linear regression which provided the ability to check residuals of the data. Each specific manikin head form dosimeter position was also analysed using this technique.

The influenced exposure and control exposures were tested using IBM SPSS Statistics 19 software for each surface type and dosimeter group using a one way ANOVA with a 95% confidence interval to determine if there is significant difference between exposures obtained through influenced or control exposures. Then, in order to determine if any differences observed between influence of reflected UV radiation from walls or corners are statistically significant, the computed ratio between influenced and control exposures was analysed for each surface type also using a one way ANOVA with a 95% confidence interval.

The ICNIRP (found in Table B-2[31]) indicates the effect of reduction in UV exposure to parts of the head due to body position as relative exposure ratios. These reported relative exposures were compared to the ratio calculated from the influence of UV reflective walls or corners compared to control exposures. The ratios were calculated by the linear regression analysis stated earlier, according to dosimeter locations on the manikin head forms.

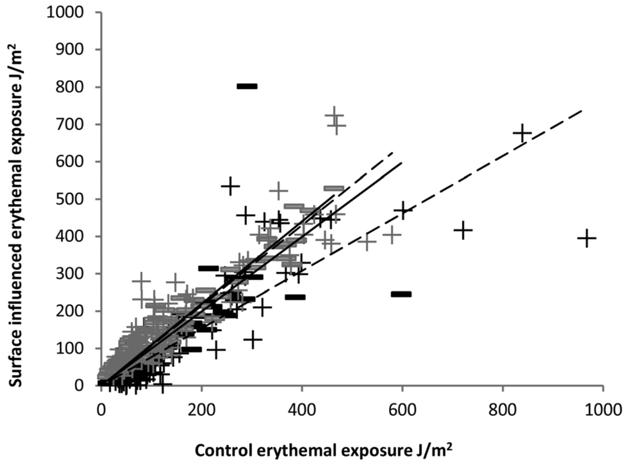

Fig. 2 Zinc aluminium trapezoidal sheeting with walls (–) and corners (+) in grey with all dosimeters from all positions on the manikin head form. Line of best fit for wall (solid): $y = 1.10x$ ($R^2 = 0.97$); corner (dashed): $y = 1.08x$ ($R^2 = 0.92$). Pale green trapezoidal sheeting with walls (–) and corners (+) in black with all dosimeters from all positions on the manikin head form. Line of best fit for wall (solid): $y = 0.874x$ ($R^2 = 0.94$); corner (dashed): $y = 0.77x$ ($R^2 = 0.85$).

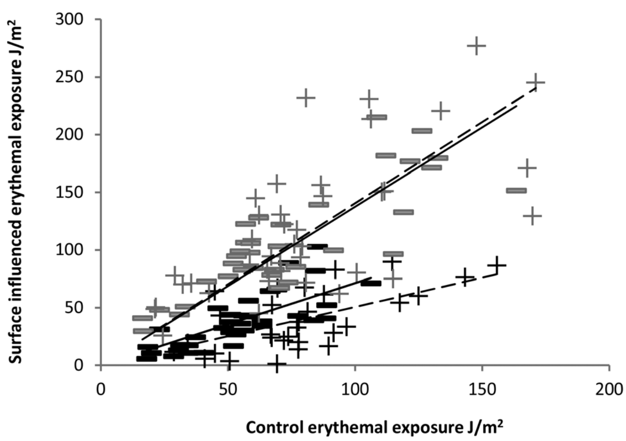

Fig. 3 Zinc aluminium trapezoidal sheeting with walls (–) and corners (+) in grey with dosimeters from facial positions only on the manikin head form. Line of best fit for wall (solid): $y = 1.38x$ ($R^2 = 0.94$); corner: $y = 1.41x$ ($R^2 = 0.88$). Pale green trapezoidal sheeting with walls (–) and corners (+) in black with dosimeters from facial positions only on the manikin head form. Line of best fit for wall (solid): $y = 0.71x$ ($R^2 = 0.89$); corner (dashed): $y = 0.51x$ ($R^2 = 0.82$).

Results

As reflective capacity of the surfaces used has been found to be variable[23] due to solar zenith angle and season, the data were analysed differently to that in the earlier study.[21] Correlating the time of day and dosimeter position, the influenced erythemal UV exposure due to surface type and construction type were compared to control erythemal UV exposure for the same time of day and dosimeter position. Fig. 2 shows the data obtained from all dosimeter positions and intervals during the exposed times for the wall and corner (structure type) of both the zinc aluminium and pale green coated steel sheeting (surface type). Fig. 3 shows the data obtained from dosimeter positions located on the face area only (forehead, nose, chin, cheeks) for all the intervals during exposure times. Upon inspection, most of the regression lines included for each group in Fig. 2 show similarity. For the zinc aluminium wall type, the linear regression is $y = 1.10x$ ($R^2 = 0.97$) and the corner type linear regression is $y = 1.08x$ ($R^2 = 0.92$). For the pale green wall type, the linear regression is $y = 0.874x$ ($R^2 = 0.94$) and the corner type linear regression is $y = 0.77x$ ($R^2 = 0.85$). In Fig. 3, which focuses on facial features, there is an apparent difference between surface types used, although apparently not as much for the construction type used. For the zinc aluminium wall type, the linear regression is $y = 1.38x$ ($R^2 = 0.94$) and the corner type linear regression is $y = 1.41x$ ($R^2 = 0.88$). For the pale green wall type, the linear regression is $y = 0.71x$ ($R^2 = 0.89$) and the corner type linear regression is $y = 0.51x$ ($R^2 = 0.82$). At the much higher exposures obtained for all surface and construction types, there is some limited data which is visible in residual tests, however isolating these higher exposure values from the data and again testing the residuals does not dramatically improve the R squared values.

To determine if construction type affected the erythemal UV exposure obtained on a manikin head form, the influenced erythemal exposure and the control erythemal exposure for each dosimeter position and time interval data were imported into SPSS. Each construction type and surface type were tested against the control and non-reflective surface control exposures using one way ANOVA with a 95% confidence interval to investigate differences and similarities. This was carried out for all the combinations presented in Fig. 2 and 3 and the results of these tests are shown in Table 1. The relative ratio

Table 1 Reflective erythemal exposure *versus* control erythemal exposure and *versus* non-reflective surface control exposure

	Control				Non-reflective control			
	Corner		Wall		Corner		Wall	
Surface type and dosimeter group	*F*-value	Sig.	*F*-value	Sig.	*F*-value	Sig.	*F*-value	Sig.
Zinc aluminium – all dosimeters	2.053	0.154	2.568	0.111	7.590	0.006	8.39	0.004
Zinc aluminium – face only	10.66	0.002	11.426	0.001	32.62	0.000	64.34	0.000
Pale green – all dosimeters	1.870	0.173	0.187	0.666	0.024	0.878	0.281	0.597
Pale green – face only	28.88	0.000	86.36	0.000	2.200	0.143	3.857	0.054

Table 2 Mean, standard deviation and one way ANOVA (95% confidence interval) for ratio of influenced erythemal exposure to control erythemal exposure and ratio of surface influenced erythemal exposure to non-reflective surface erythemal exposure

	Relative ratio (control)				Relative ratio (non-reflective control)			
	Mean (standard deviation)				Mean (standard deviation)			
Surface type and dosimeter group	Wall	Corner	*F*-value	Sig.	Wall	Corner	*F*-value	Sig.
Zinc aluminium – all dosimeters	1.34 (0.37)	1.39 (0.59)	0.523	0.471	2.75 (2.73)	6.69 (16.5)	5.037	0.026
Zinc aluminium – face only	1.54 (0.38)	1.57 (0.57)	0.099	0.754	4.46 (3.55)	12.8 (25.5)	3.648	0.060
Pale green – all dosimeters	0.82 (0.40)	0.69 (0.44)	4.152	0.043	1.21 (0.43)	1.40 (0.81)	3.534	0.062
Pale green – face only	0.67 (0.28)	0.50 (0.31)	5.720	0.020	1.33 (0.34)	1.63 (0.86)	3.598	0.063

was computed for the influenced (for each surface and construction type) and control erythemal exposures, and one way ANOVA with 95% confidence intervals were run between the corner data ratios and the wall data ratios (Table 2). The process was repeated with the influenced erythemal exposure and non-reflective surface control exposure. In the instance of using the control erythemal exposure data, the results indicate that despite the slightly higher ratio for a corner compared to a wall (made with zinc aluminium coated steel) there was no statistically significant difference found between the construction types. Therefore, even for highly UV reflecting surfaces such as zinc aluminium coated steel, the presence of a corner does not significantly influence daily erythemal UV exposures any more than a wall of the same material. This does not translate to considering the sky view (non-reflective surface) control, where significant differences are observed for zinc aluminium between a wall and a corner. This observed effect however is not due to reflective effect, but rather the significant impact that sky-view has on ambient erythemal UV exposure, which has already been confirmed in the tested data in Table 2. When considering the data for the pale green coated steel data, the relative ratio shows much more variation. There is a statistically significant difference between the erythemal exposures obtained for a wall and a corner. This statistical significance is increased when investigating only facially positioned dosimeters.

Body features themselves affect the expected erythemal exposure due to orientation of the surface of the body. In standard conditions, without the presence of reflective surface, the ICNIRP[31] provides the relative exposures that can be anticipated for certain facial and body positions including vertex,

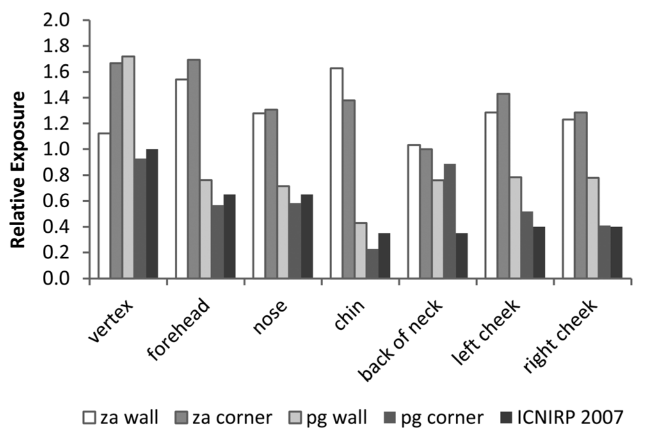

Fig. 4 Zinc aluminium coated and pale green coated trapezoidal steel with daily averaged relative exposures for wall, corner and ICNIRP relative exposures for comparison.

forehead, nose, chin, back of neck, and cheeks. The data obtained in this study for these body sites were used to calculate the average daily relative exposure ratio, and compared to the relative exposure factors provided by the ICNIRP (Fig. 4). Zinc aluminium coated steel surfaces with high UV reflective capacity influence the expected relative exposure outcomes of an outdoor worker located in the vicinity of such a surface, at times approaching twice the relative exposure listed by the ICNIRP. However, when a worker is located near a paint coated (pale green) surface of the same structure types, the relative exposure values observed are approximately the same, or less than the values provided by the ICNIRP.

Discussion

Fig. 2 and 3 indicate similarity between construction type influence for zinc aluminium coated steel surfaces with no statistically significant difference between erythemal exposures observed (Table 2). This might be considered fortunate, since the influence of this particular UV reflective surface has on personal UV exposures, is relatively high. This is not the case for pale green surfaces which indicates there is no statistical difference observed between a pale green corner and non-reflective control exposure for the all dosimeters group (Table 1), with a statistically significant difference between wall and corner ratios (Table 2). Therefore, it may be concluded that corners constructed with this surface type are more effective at reducing UV exposure than zinc aluminium surface types due to a combination of restricting sky view and lower UV reflective capacity.

Fig. 2 for zinc aluminium indicates different reflective ratios (the slope for the regression lines) compared to Fig. 3, however these lower ratios are most likely to be caused by the inclusion of dosimeter sites that should receive approximately the same exposures for the control as the surface influenced head form. These dosimeter sites include back of head, back of neck, and potentially the shoulders. The R^2 coefficient drops between the groups of all dosimeters and face only dosimeter, while the erythemal ratio (slope) increases (Fig. 3), however this increase may also be attributed to the reduced number of data values. The number of dosimeters for the face is 40% of the total number of dosimeters used for the entire head form. Fig. 2 and 3 also provide a system that account for time of day, that was calculated individually in the previous study.[21] It is appropriate at this point to discuss the usefulness of using the regression coefficient or slope to determine reflective ratio as opposed to the mean reflective ratio obtained through the SPSS analysis in Table 2. If we insert the mean as a line into Fig. 2 and 3 and compared the variance about the line with all the data values, we will find that the size of the residuals would be much higher than those created for the regression line. Therefore the regression line is a better fit and provides an expression for the influence of the surface and construction type compared to a control, even with variable SZA and erythemal exposure. Previous studies that may have used means to determine ratios should consider using regression to calculate reflective ratios to better reflect the overall reflective behaviour of a surface, compared to a control erythemal exposure. Additionally this analysis technique would be recommended for any new studies seeking to obtain more accurate reflective ratios. Readers will note that the data provided in Fig. 4 is calculated using the regression method, as compared to Fig. 4 in the previous study[21] which uses the averaging method.

Pale green coated steel shows differences in both Fig. 2 and 3 when considering the influence of a wall or corner and this is confirmed through statistical significance (Table 1), with the statistical significance increasing when focusing on facial sites that are more influenced by the surrounding surfaces. Previous work on understanding UV reflection from non-horizontal surfaces[22,23] suggests that pale green (paint) coated steel surfaces reflect UV radiation differently to zinc aluminium coated steel surfaces. This is likely due to more diffuse reflection occurring rather than specular reflection, where the angle of reflected irradiance does not depend on incident irradiance, as a result of the paint molecules causing the effect of backscatter to incident UV radiation. It appears that the added dimension of a corner blocks ambient UV irradiance from the head form. The influenced UV exposure from a pale green corner or wall as compared to the non-reflective surface control exposure indicates no significant difference between UV exposure obtained and therefore behaves similarly to a low or non-reflecting surface type.

The reduction of UV irradiance due to pale green coated steel therefore also provides an important factor when considering relative exposures of the face and body as shown in Fig. 4. Data provided by ICNIRP[31] as plotted in the figure, indicate that if a worker was in the vicinity of a pale green coated steel corner, the relative exposure obtained for the vertex, forehead, nose, chin, and cheeks would be comparable or even less than the relative exposure obtained by a person not in the vicinity of any wall or corner. The relative exposures found on face positions influenced by zinc aluminium coated steel exceed the ICNIRP relative exposure. As a result, this suggests that if workers must work near vertical surfaces such as walls or corners, workers would benefit by working with surfaces that are similar in construction as the pale green coated steel as opposed to the zinc aluminium coated steel to assist in reducing excessive UV exposures. There are paint coatings available that additionally insulate against thermal radiation and have been shown to have comparable UV reflection to standard paint coated metallic surfaces.[32]

Using the reflective ratios obtained in this study, the ability to determine a UV reflective factor should be possible and will be similar to cloud modification factors[33,34] or mean protection factors.[35] UV reflective factors could be disseminated to outdoor workers, who could use this knowledge to assist managing their personal UV exposure. Additionally, this knowledge may enable workplaces to make UV aware choices such as using paint coated surface types as opposed to zinc aluminium coated surface types to reduce increasing UV exposure to workers in certain construction situations. With little difference between influence of erythemal exposure due to surface type for zinc aluminium coated steel, this information is also useful for determining the overall effect of a UV reflective of a surface. This means that walls and corners of this particular surface type will contribute approximately the same influence for highly UV reflective surface regardless of construction type. In turn this should provide easy to express UV reflective factors for highly reflective surface without needing to account for construction type. In the future, when disseminating the collected information of this study and others to Occupational Health and Safety bodies, the ability to have predictable effect caused by a surface (regardless of construction configuration) may allow an effective overall exposure factor to be calculated. Therefore this could provide the construction industry and outdoor workers the ability to take more control of their work behaviour and protective strategies for reducing excessive UV exposure when at work.

This is by no means a simple solution to reducing excessive UV exposures obtained by outdoor workers; however it may contribute by assisting workers to manage their own individual UV exposures. Using personal protective equipment (PPE) such as hat, sunscreen, long sleeved shirts and sunglasses, as well as seeking shade where possible, and staying out of the sun during the maximum UV exposure periods are all effective measures to reduce UV exposure to more appropriate levels. However, some studies show that this is not enough, and that educating workers and their workplaces about UV radiation increases the effect of using prevention strategies in order to reduce UV exposures to outdoor workers.[8,36–39]

Conclusions

The effect of a corner *versus* wall in influencing the UV exposure of an outdoor worker is very similar for highly UV reflective surfaces and different constructive configurations do not affect the reflective influence. However for less UV reflective surfaces, a worker positioned near a corner rather than a wall is able to reduce UV exposure by blocking some of the ambient UV radiation by limiting sky view. Therefore construction type for the less UV reflective surface is potentially beneficial to outdoor workers. A low UV reflective surface should be recommended for use by the construction industry as opposed to more highly UV reflective surfaces to assist workers in managing UV exposure levels should they happen to work in such areas. The lack of difference in effect on UV exposure between different construction types for highly UV reflective surfaces provides an opportunity that may allow a UV reflection factor to be developed for highly UV reflective surfaces regardless of position and construction type in an urban area. In order to calculate these UV reflective factors, the use of linear regression analysis is advised for greater understanding and accuracy with regards to the influence to UV exposures.

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