Proceedings of 8th Windsor Conference: ***Counting the Cost of Comfort in a changing world*** Cumberland Lodge, Windsor, UK, 10-13 April 2014. London: Network for Comfort and Energy Use in Buildings, http://nceub.org.uk

Solar reflected glare affecting visual performance

Dr Luisa Brotas[1] and Dr Jan Wienold[2]

1 Low Energy Architecture Research Unit, Sir John Cass Faculty of Art, Architecture and Design, London Metropolitan University, UK, l.brotas@londonmet.ac.uk
2 Interdisciplinary Laboratory of Performance-Integrated Design, EPFL ENAC IA LIPID, Switzerland, jan.wienold@epfl.ch

Abstract
Visual comfort is important to the wellbeing of people and their productivity. However, too much light in the field of view can cause discomfort and disability glare. Under certain conditions it can even cause accidents. This paper addresses the disability glare created by veiling glare and the effect it may have of reducing the visual performance in outdoor spaces. Veiling glare is a particular case when light is reflected off a surface and causes annoyance or impairment of a task to the person in a particular view angle. Two factors that determine the nature and magnitude of veiling reflections are the specularity of the surface being viewed and the geometrical relationship between the observer, the surface and any source of high luminance. Different methods to assess disability glare exist but there is still no clear understanding on criteria to judge an outdoor scenario. A case study where reflected glare form Photovoltaics overlooking a building is of particular concern is presented.

Keywords: glare, reflected sunlight, visual comfort, Photovoltaic

1 Introduction
Visual comfort is important to the wellbeing of people and their productivity. Daylight is often acknowledged as contributing positively towards visual comfort. However, under certain conditions can be a negative effect and create discomfort or disability glare. Glare may occur when there is too much light, when the luminance range is too high and is within a given view angle of the observer. The wrong combination of these may have an impact on the ability of a person to perform a visual task.

Disability glare created by veiling glare may reduce the visual performance in outdoor spaces. This may be particular relevant for air and road traffic where impairment of the visual task can even be the cause of accidents.

2 Glare assessment
Glare may occur when there is too much light, when the luminance range is too high and is within a given view angle of the observer. The wrong combination of these may have an impact on the ability of a person to perform a visual task. Glare can be quantified according to five classes:

- Saturation,
- Adaptation,
- Disability,
- Discomfort,
- Overhead glare.

Veiling glare is a particular case when light is reflected off a surface and causes annoyance or impairment of a task to the person in a particular view angle. Two factors that determine the nature and magnitude of veiling reflections are the specularity of the surface being viewed and the geometrical relationship between the observer, the surface and any source of high luminance. (SLL 2009)

This paper will only address the disability glare created by veiling glare and the effect it may have of reducing the visual performance.

Disability glare is an effect caused by the scattering of light in the eye which reduces the luminance contrast of the retina image. The disability glare formula was originally developed by Stiles and Holladay, and later with Crawford. Their work was further developed by Vos who highlighted the importance of the eye pigmentation and the age of the observer. In 2002, CIE published 3 disability formulae in the form of report 146. (Vos 2003a, 2003b; CIE 1999, 2002) These are based on the Stiles-Holladay glare equation and take into account the age of the observer, the ocular pigmentation and extend the angular domain over which the equations are valid. They all describe the Veiling Luminance due to a point glare source at an angle to the line of site that gives rise to an Illuminance in the plane of the observer's eye. All include age as a factor. The CIE General Disability Glare equation has a glare angle validity in degrees between 0.1° and 100° and also includes an eye pigmentation factor which plays a role at glare angles greater than 30°. A simplified definition in the CIE Age adjusted Stiles-Holladay Disability Glare equation with a restricted validity domain of 1° and 30°. The CIE Small Angle Disability Glare equation is a simplification applicable to the domain of the narrow angles between 0.1° to 30°. In different fields of application different degrees of accuracy are required. (CIE 2002a)

Vos addresses the Luminance distance to account for the Detection distance of an obstacle/focal point under conditions of glare. This is also affected by the age of the observer. (CIE 1999)

In disability glare for practical lighting considerations and only considering the physical phenomena of light scatter, the effects from multiple light sources are additive and extended light sources may be integrated. (CIE 2002b)

3 Calculation methods

In outdoor tasks or overlooking windows with reflected solar dazzle ahead it is of major importance to assess the magnitude of disability glare as the impairment of vision can cause accidents.

There are three dimensions to glare: temporal, spatial and intensity. For these it is important to predict the times of day and year when solar dazzle can occur. Because of its high intensity, one may assume that if solar refection is within the field of view it will cause glare. Therefore it may be sufficient to estimate the period and position when it may occur.

Previous research highlights that it is not important to quantify the intensity of the reflected source on the assumption that any reflected glare will cause nuisance. However the degree to which it is an annoyance or impairment is strongly related to the view field. It also becomes relevant how to mitigate its effect. Correction measures will depend on a case to case basis. Littlefair (1987a and 1987b) provides the formulae to assess and quantify solar dazzle reflected from glazed facades. A graphical method (stereographic projection) to predict the periods and times of the year when solar dazzle may occur is also presented. Computer simulation programs are also available. (Wienold, 2006).

In particular situations when the focal point is surrounded by very bright sources (ie traffic lights seen against a bright facade) it may be important to assess disability glare with a CIE equation.

Schiler (2009) and SSK (2006) refer to absolute glare and relative glare. The former occurs when there is a (source of) luminance in the field of view which is sufficient to cause damage to the eye, no matter what the relative background level. Relative glare occurs when the eye can adapt to the background luminance level in a field of view but the contrast between a specific luminance in the field and the background exceeds some ratio. Relative glare was originally defined for interior conditions. Absolute glare was not a strong priority unless a very luminous light source was in place. That could be from an artificial light source or from reflected sunlight in a facing surface view though a window. Outdoors we may face much higher luminance sources, ie the sun or reflected sunlight. There is no point in addressing contrast ratios and absolute glare could be more relevant. However as previously highlighted solar dazzle will inevitably be glaring so is the position of the glare source and the temporal period of it occurrence that is important to assess.

Common computer simplifications in terms of geometries and definition of surface coatings have a major impact in the effective reflectance of light in facades in daylight studies. Mirror material commonly replace glazing surfaces are assumed to aggravate the scenario as they maximising the specular reflectance compared to glass where the reflected component will vary for different angles of incidence, and where part of the flux will be transmitted indoors. Not all views of a glazed façade are glaring. Clearly the reflectance is strongly dependent on the coating characteristics of the glazing systems. Whereas this may be considered acceptable to highlight areas of potential glare, glass coatings and PV finishes may scatter more light and therefore aggravate the effect of reflecting light. To quantify the intensity and shape of the reflection it is necessary to characterize and model the bi-directional reflection properties of the surface. See Figure 1.

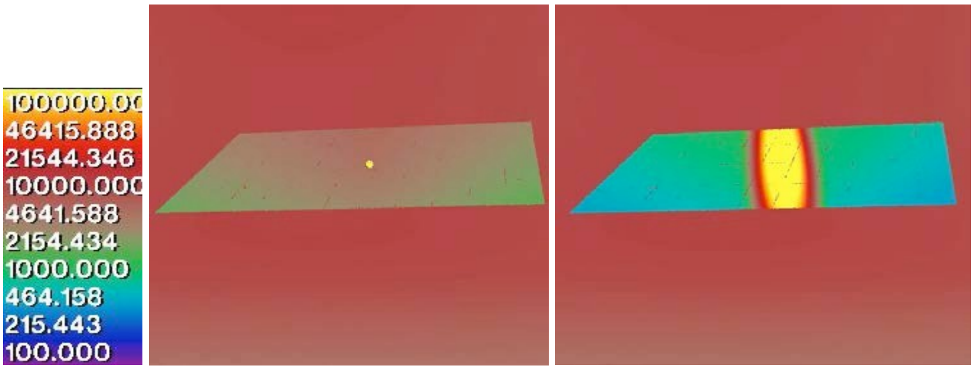

Figure 1. Falsecolor representation of the simulation of a normal glazing reflection where the the sun is reflected as a point in the left image, and forward scattering properties where the sun is reflected as a band (source Wienold 2013)

Wienold (2013) presents a newly developed calculation method suitable for simulating the glare potential from PV installations, and to evaluate the effects of different reflection properties of glazing and their anti-reflective coatings. The method calculates the luminance of the reflection and the duration of glare conditions throughout the year. RADIANCE is the lighting software engine behind the calculation.

While indoors scenarios and discomfort glare have been object of several glare indexes, including the recent Daylight Glare Probability (Wienold, 2006) it is recognised that glare from daylight sources is relatively poorly understood (Osterhaus, 2005). This is vaguer when quantifying disability in outdoors. Previous literature found that an absolute luminance value above a certain threshold can be applied. This has been adopted in RADIANCE engine as to calculate areas of glare. Ward two step method does not calculate glare per se but defines possible sources of glare. In the first instance the average luminance (similar to the background luminance) is calculated, the second step looks for luminance within the field of view that are greater than 7 times that value. (Ward 1991)

Conversely CIE Disability equations are being tested within Evalglare software by the authors and so is the mapping of the glare source in the visual field. When sources of glare are superimposed in an overall visual field mask, highlighted areas of disability glare are also related to areas of high impact in the restricted field of view: less than 3°, between 3° and 30°, in the influence of 60° and 100° within the view direction.

For outdoor spaces and for traffic situations it is not the time or duration of the occurrence of glare that should be investigated as glare should be prevented. It then becomes important the size and location of the glare source in regards to the view point as well a maximum allowed luminance below the absolute glare thresholds. Mitigating measures need to the investigated.

The situation of dazzle glare from a PV panel or a sunlight reflection of a glazing facade it is also important to also address the temporal basis: its duration and time of occurrence. An analogy can be made to studies on thermal comfort in particular the recent publication by CIBSE (2013) on how to prevent overheating in buildings in Europe. Three criteria are presented and a space is classed as overheating if fails any two out of three criteria:

" (1) The first criterion sets a limit for the number of hours that the operative temperature can exceed the threshold comfort temperature (upper limit of the range of comfort temperature) by 1 K or more during the occupied hours of a typical non-heating season (1 May to 30 September).

(2) The second criterion deals with the severity of overheating within any one day, which can be as important as its frequency, the level of which is a function of both temperature rise and its duration. This criterion sets a daily limit for acceptability.

(3) The third criterion sets an absolute maximum daily temperature for a room, beyond which the level of overheating is unacceptable." (CIBSE, 2013)

For daylight analysis the problem is further aggravated as the eye has an ability to adapt to a wide range of luminance. An absolute threshold and an 'hours over' criterion may be a starting criteria. The relative luminance approach defining where high luminance sources are in regards to the average surrounding visual environment may be also applicable for indoor assessments. Then the field of view with a glare angle validity in degrees between a range defined in CIE disability glare formulae addresses its influence at the eye illuminance level. These are already or currently under evaluation with Evalglare software.

4 Results

Table 1presents the results of glare calculation quantifying the duration of glare on different balconies. Days with half an hour or an hour are estimated. This goes in line with the first criterion adopted for assessing overheating in thermal comfort studies. What is still difficult to define is the quantification of this criterion. How much is too much? Different tasks and different places with require different thresholds and will certainly produce different satisfaction levels and productivity results. When does a sun patch in a dwelling changes from a delight to an annoyance or impairment?

Table 1. Exemplary results of the glare calculations quantifying the duration and of glare on a balcony

		year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Balcony 1st	sum h glare	77.9	8.6	15.9	13.1	0	0	0	0	0	5	19.3	11	5
	Days > 30min Glare	72	9	12	12	0	0	0	0	0	5	17	13	4
	Days> 1 h Glare	22	1	7	5	0	0	0	0	0	0	6	3	0
Balcony 2nd	Sum h Glare	75.7	2.8	16	20.3	0.9	0	0	0	0	12	18.6	5.2	0
	Days > 30min Glare	55	2	12	17	1	0	0	0	0	8	11	4	0
	Days> 1 h Glare	34	0	8	10	0	0	0	0	0	5	9	2	0
Room 1st	Sum h Glare	41.4	9.3	6.2	0	0	0	0	0	0	0	6.3	11.3	8.3
	Days > 30min Glare	41	8	5	0	0	0	0	0	0	0	5	14	9
	Days> 1 h Glare	1	1	0	0	0	0	0	0	0	0	0	0	0
Room 2nd	Sum h Glare	38.6	6.2	9.6	2.6	0	0	0	0	0	0	9.8	7.3	3.1
	Days > 30min Glare	28	5	9	1	0	0	0	0	0	0	6	7	0
	Days> 1 h Glare	7	0	0	0	0	0	0	0	0	0	7	0	0

In an indoor condition the view outside to a highly reflected surface can be estimated as disability glare. Figure 2 provides an example of an absolute luminance when assessing disability glare from sources with high luminance values. The size and position of the glare source is of importance, much more than its intensity, assumed to exceed absolute thresholds. The occupant opportunity to adaptation namely operating blinds may be of extreme importance to minimize glare and its effect on the performance of the task.

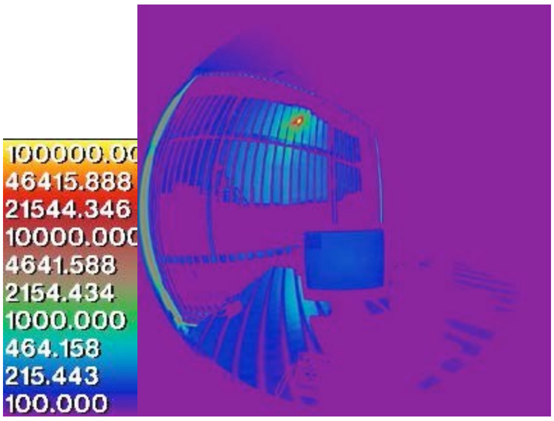

Figure 2. False color HDR image of the user assessments using the vertical foil shading. The luminance of the sun is comparable to the reflected luminance by a PV panel from the same direction (source Wienold 2013).

5 Discussion and Conclusion

Different methods exist to assess glare in indoor environments. These tend to assess discomfort glare. Disability glare poses a more difficult task as by its impairing nature can cause accidents. Calculation methods presented are able to estimate the glare effects caused by external surfaces like PV panels or dazzle glare from facades. However, there is still no consensual agreement on which method to adopt and even less on the criteria associated. There are clearly situations where disability glare cannot occur. Likewise the temporal degree and its subjective judgement call for further studies. Recently advances in thermal comfort have put forward a set of criteria that could serve as the basis to the development of a similar approach to glare. Depending on the type of glare under assessment, ie discomfort or disability different criteria may need to be satisfied. Similarly to the adaptive comfort method, based on real data in buildings, glare should be based on field studies. There are still missing reliable studies on glare quantification in outdoor cases, when the sun is reflected to validate different criteria and substantiate a solid evaluation method. Nevertheless simulation methods are important to predict and prevent errors like recently examples in Los Angeles and London where reflected sunlight from facades are causing damage and impairment to neighbour spaces and its occupants.

References

BSI (2007) *BS EN 15251:2007 Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics*. London: British Standards Institution

CIBSE (2013*) TM52:2013. The limits of thermal comfort: avoiding overheating in European buildings*. London. The Chartered Institution of Building Services Engineers

CIE (1999) *CIE Collection 1999: Vision and Colour: Physical Measurement of Light and Radiation*, 135/1 Research note: Disability Glare, Commission Internationale de L'Éclairage, pp.1-10

CIE (2002) *CIE Collection on Glare 2002: Equations for disability glare*, 146 CIE TC 1-50 report and *Glare from small, large and complex sources,* 147 CIE TC 3-01 report Commission Internationale de L'Éclairage

Littlefair, P., (1987a) Prediction of Reflected Solar Dazzle from Sloping Facades, Building and Environment, 22(4), pp.285-291

Littlefair, P., (1987b) Solar dazzle reflected from sloping glazed facades, IP 3/87, Building Research Establishment, Garston

Osterhaus, W. K. E., (2005) Discomfort glare assessment and prevention for daylight applications in office environments. Solar Energy, 79(2):140–158.

SLL (2009) *The SLL Lighting Handbook*, London: The Society of Light and Lighting

Schiler, M., (2009) Examples of Glare Remediation Techniques: Four buildings, in proceedings PLEA 2009

SSK, (2006) Blendung durch natürliche und neue künstliche Lichtquellen und ihre Gefahren, Empfehlung der Strahlenschutzkommission (SSK), Bonn

Vos, JJ., (2003a) On the cause of disability glare and its dependence on glare angle, age and ocular pigmentation. *Clinical and Experimental Optometry* 86(6), pp.363-370

Vos, JJ., (2003b) Reflections on glare. *Lighting Research and Technology* 35(2), pp.163-176

Wienold, J. and Christoffersen, J., (2006) Evaluation methods and development of a new glare prediction model for daylight environments with the use of CCD cameras. *Energy and buildings*, 38970, pp. 743-757

Wienold, J., (2013) Glare caused by reflections of solar panels, in proceedings, LuxEuropa 2013