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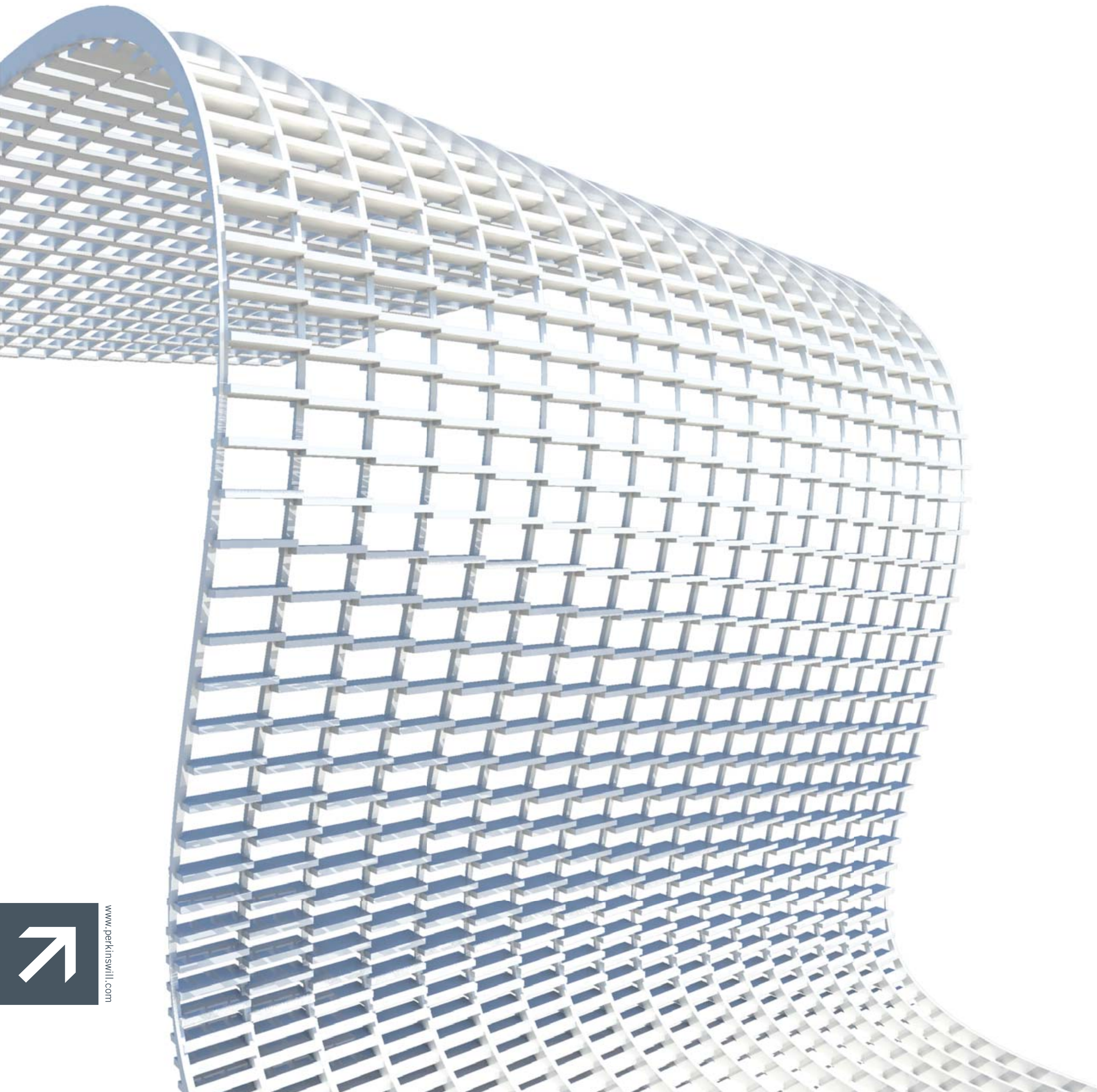

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UNDERSTANDING GLARE:

Design Methods for Improving Visual Comfort

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ABSTRACT

Daylight harvesting in architecture is a complicated task as the most prominent characteristic of daylight is its variability. There are many methods of estimating how daylight will benefit spaces, but too often the potential for glare is not properly addressed during design. This is especially prevalent in office space environments. A far too common scene is an office space with paper or foil taped to the glazing to keep glare sources from disturbing occupants. This article outlines what glare is, how it can be measured, when it is critical to analyze the potential for glare and solutions to keep occupants comfortable and at the same time optimize daylight harvesting throughout the year.

KEYWORDS: daylight harvesting, glare, passive shading, solar control, visual comfort

1.0 INTRODUCTION: WHAT IS GLARE?

In the world of daylighting design it is important to understand the terms “glare” and “brightness” in order to use the proper vocabulary when designing spaces to achieve occupant visual comfort. A common definition for glare is a very harsh, bright, dazzling light. Brightness is often used incorrectly to explain the illuminance in a space. Brightness should only be used for non-quantitative references to physiological sensations and perceptions of light, not as a synonym for the photometric terms illuminance and luminance or the radiometric term *radiance*[1].

The IESNA indentifies glare as two sensations, disability glare and discomfort glare. Disability glare is defined as “the effect of stray light in the eye whereby visibility and visual performance are reduced”[2]. Discomfort glare is defined as “glare that produces discomfort.” It does not necessarily interfere with visual performance or visibility[2]. An example of disability glare is the sensation a person experiences on a bright sunny day surrounded by snow. The overall luminance values of the environment are too bright for the eyes to handle without shading or lowering the overall luminance values with sunglasses. An example of discomfort glare is the sensation one feels when working at a computer screen and having direct sunlight in the field of view such that it is difficult to read the monitor due to the high luminance values of the direct sunlight.

In order to understand disability glare and discomfort glare, one must understand the difference between luminance and illuminance values. Though most lighting designs are based upon illuminance values, the perceived brightness of our environment that can cause visual discomfort is best described in luminance values. Luminance is the luminous intensity that is given off at a point on a surface at a given direction. It is a metric to describe the amount of light that is emitted from an object at a specific angle. Illuminance is the total amount of light from all angles on a surface. It is a ratio of the quantity of light reaching a surface and the surface area that is illuminated. Most designers are aware of illuminance, but luminance is rarely discussed. It is important that individuals understand luminance as it is the best representation of what the human eye actually perceives.

Though the world of science has a solid understanding of the physics of light, the human response is not as clear, since it is a perceived physiological response to lighting conditions. For example, studies have shown that relative luminance contrast is not the only variable that can effect discomfort glare[3]. Individuals are more likely to experience glare under artificial lighting condi-

Figure 1: Examples of disability and discomfort glare sources.

tions than under daylight due to the fact that people are able to handle greater levels of relative luminance contrast in their field of view with natural light.

Researchers know that the following items do impact discomfort glare: light source luminance, luminance of the field of view, relative visual scale of the light source and relative location of the light source. All of these factors must be combined and compared relative to one another to get a sense of the probability of discomfort glare in a space.

Indirect physiological impacts of glare can include red and itchy eyes, headaches, gastrointestinal issues and fatigue[3]. It is challenging to measure the actual impacts of lighting conditions on individuals as all of these physiological impacts can have multiple causes. The responses will also vary significantly from individual to individual. All of this makes objective measurements for informing design quite challenging. Trends in physiological impacts among occupants in existing projects are a definite red flag that lighting conditions should be analyzed to see if they are the cause.

2.0 METHODS FOR MEASURING GLARE

There are a number of different methods available for measuring glare. Many of them are far more appropriate for artificial lighting than daylighting. Examples of glare measurements appropriate for artificial lighting include the Visual Comfort Probability (VCP) and the CIE's Unified Glare Rating (UGR)[4].

VCP has limited applicability to certain lamp technologies but UGR has been more widely adopted. UGR is usually in the range of 10 to 30 with higher numbers representing greater discomfort[5]. In offices the highest UGR value that should be allowed is 20. Lighting manufacturers regularly publish UGR values for luminaires in order for designers to know which luminaires create less glare in specific spaces. Radiance, a backwards ray-tracing daylight simulation system, has the ability to accurately calculate luminance values and glare indexes for architectural spaces. Radiance is a free software program developed by the Lawrence Berkeley National Laboratory (LBNL) that most accurately predicts these results. An example of a UGR output and Radiance image is below for a proposed atrium renovation at Simon Fraser University.

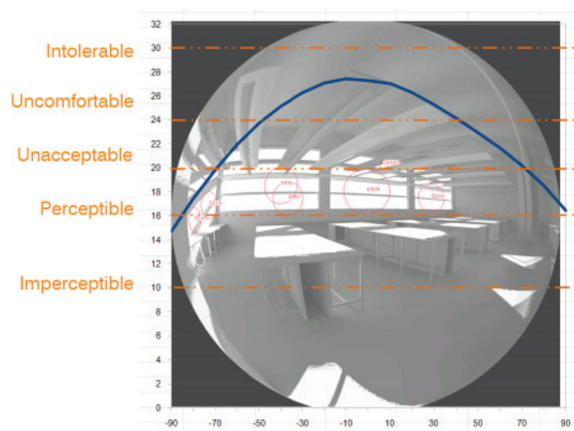

Figure 2: SFU – Atrium concept showing UGR values.

A new glare metric is being developed at the Fraunhofer ISE in Germany, known as Daylight Glare Probability (DGP), which is meant to better estimate the probability of glare in daylight conditions[6]. DGP has tested more subjects' responses to discomfort glare than previous glare metrics. Tests show a better correlation between user assessments and the glare formula's calculations. In addition to validating discomfort glare predictions, researchers at the Fraunhofer ISE have also developed software to calculate DGP with Radiance[7]. This is very promising as practitioners need better tools to estimate the potential for glare during the design process. In addition to calculating DGP, it calculates values of URG and VCP values along with several more glare metrics all at once.

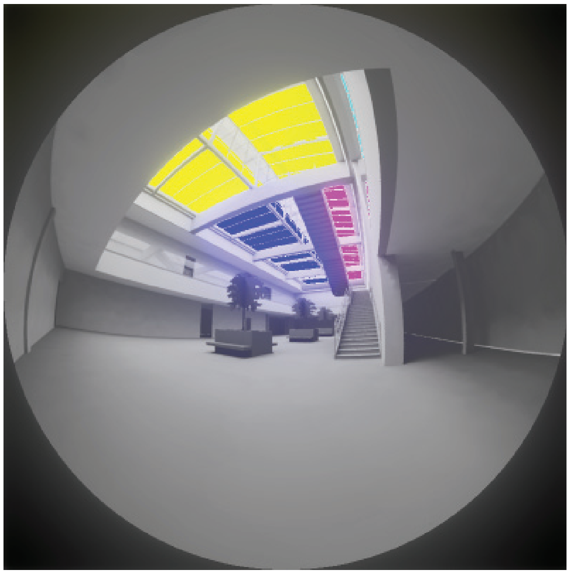

Figure 3: SFU – Atrium concept showing DGP glare sources.

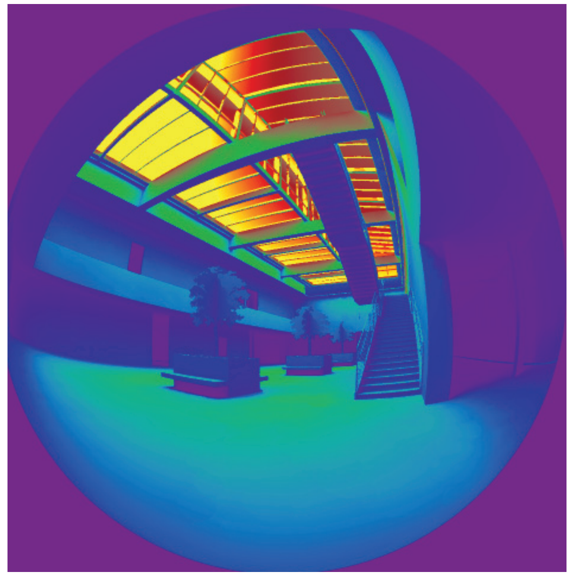

Figure 4: SFU – Atrium concept showing false color illumination.

3.0 CRITICAL SPACES TO CONTROL GLARE

With an understanding of what glare is and how to measure it, the next steps are to isolate areas of high concern. Disability glare is highly uncommon inside buildings, so the analysis and design needs to focus on the potentials for discomfort glare. This is applicable to designers, building owners and building operators as a building's design and the manner in which it is operated have direct impacts on the potential for discomfort glare.

In order to properly design building envelopes to harvest daylight and control discomfort glare, it is critical that designers consider an occupant's relationship to glazing. This relationship goes beyond an occupant's location in space in plan or section. Our eyes experience the entire field of view so it is critical that any lines of sight to glazing on any surface be considered, since discomfort glare can come from anywhere in the field of view. This is best measured using fish eye camera views generated with computer simulations. Radiance can be used to help identify glazing with the potential for creating discomfort glare.

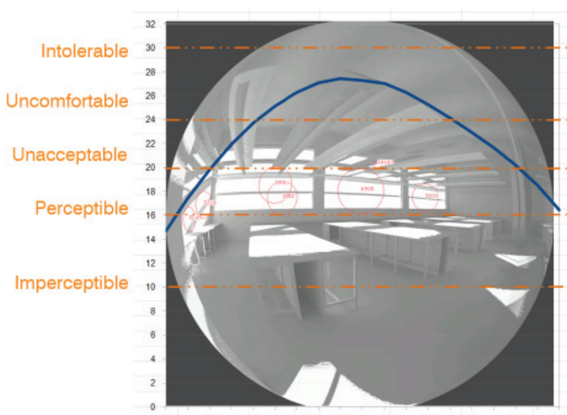

Figure 5: EEEL – Typical teaching laboratory Radiance luminance view showing UGR values.

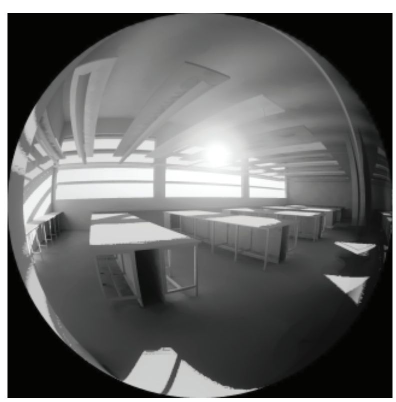

Figure 6: EEEL – Typical teaching laboratory Radiance luminance view with a human eye filter showing the relative perception of light.

Before running any simulations, there are elements part of an envelope design that should be carefully considered as potential sources of visual discomfort. In general, any glazing elements (whether transparent or translucent) that have direct lines of sight to the upper portions of the sky should be considered as potential sources of glare. Rooms with proportionally high ceilings are especially susceptible to this as occupants can have direct lines of site to the top of the sky dome where the highest average luminance values occur. Any translucent materials (e.g. fritted glass, Kalwall or Okalux) should also be carefully considered as the diffusion of light can be such that the relative luminance of a material creates significant glare in a space.

Once potential glare sources have been identified they will need to be controlled. Solar control devices that help manage glare need to be designed with ownership and control in mind. Ownership in this context refers to the ability to control shading devices. This is very important to understand in office environments as individuals may not have ownership over the controls of shading devices that can eliminate sources of discomfort glare. For example, it is possible that a window providing wonderful daylight for part of an office is creating visual discomfort for another portion.

When discomfort glare is possible the following questions need to be raised: Who has ownership over controlling solar control devices? If someone lowers shading devices who is responsible for raising them back up once the source of discomfort has passed? If the devices are automated, is there a manual override in case the building controls are not sophisticated enough to handle all the hours of potential discomfort glare? Are automated controls working to raise shading devices once the hours of potential glare have passed? Who is responsible for tuning the controls once a building is occupied to ensure occupant comfort? All of these questions need to be asked during the design process to create buildings that are visually comfortable to occupy year round.

4.0 SOLUTIONS TO KEEP OCCUPANTS COMFORTABLE AND TO MAXIMIZE DAYLIGHT HARVESTING

The best place to start when studying the potential for discomfort glare during the design process is to do a direct sun study. This involves assessing a design space-by-space and examining how direct sunlight will affect working surfaces throughout the year. A good metric to follow is the "thirty minute rule". This establishes a baseline for good solar and potential glare control by ensuring that direct sunlight is not on any working surface for more than thirty minutes for any day throughout the year. This recognizes the fact that direct sunlight in a building is not necessarily a bad thing until it becomes a long term visual disturbance. If direct sunlight is hitting a working surface then the glazing that is the source of the direct sunlight will require some level of solar control. Stereographic diagrams are an excellent way to understand how direct sunlight hits working surfaces throughout the year. These diagrams measure a point in space and show graphically an annual sunpath and the hours and months that the point receives direct sunlight.

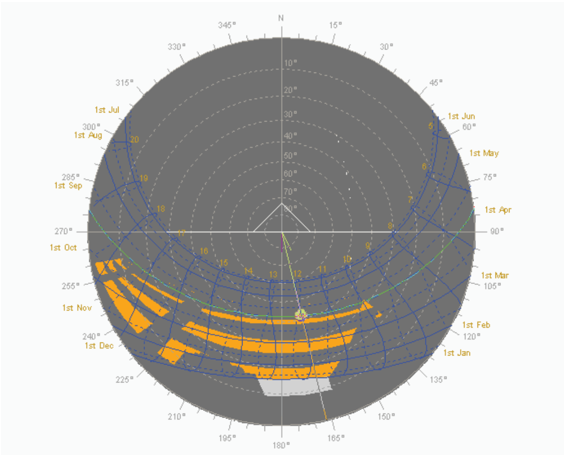

Figure 7: EEEL – Typical teaching laboratory stereographic diagram.

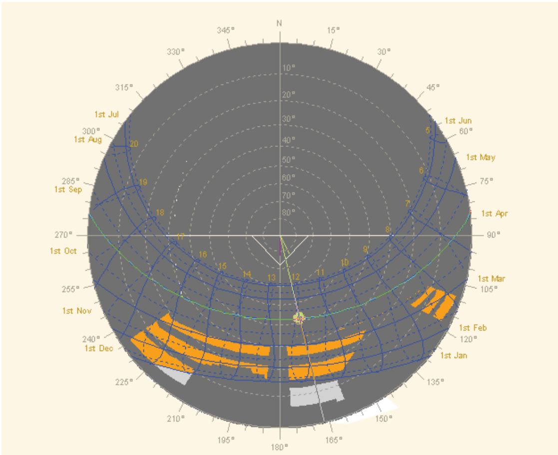

Figure 8: EEEL – Typical teaching laboratory stereographic diagram.

The ultimate goal for a project is to control daylight such that no direct sunlight reaches working surfaces throughout the year. This will likely require some level of active solar control devices to properly manage direct sunlight. These targets reduce the likelihood of discomfort glare on working surfaces, but there is still the potential for visual discomfort in an occupant's field of view.

One of the best design strategies for any project to optimize daylight and control the potential for glare is to separate daylight glazing from vision glazing. Daylight glazing typically includes anything above 2m (7ft) though it can be higher depending on the size of the room relative to a façade. The following diagram shows this in elevation. Note that glazing below 0.75m (2.5 ft) adds very little to help daylight a space while adding solar heat gain.

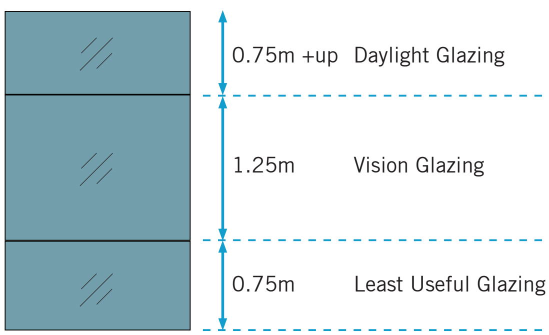

Figure 9: Typical proportions for vision and daylight glazing.

Passive shading solutions are the lowest maintenance option for controlling the potential for visual discomfort. A good example of a passive device for controlling the potential for glare is a light shelf. It is a common misconception that light shelves help bring more light deeper into a space. They actually tend to reduce the overall light level in a space throughout the year (especially in overcast sky conditions). What light shelves do very well is separate daylight glazing from vision glazing so that direct lines of site to the upper portions of the sky are masked from occupants. This is very important as the sky has much higher luminance values on average in the upper portions of the sky dome. A light shelf shields occupants from potential glare in this zone while creating the potential to control vision glazing separately from daylight glazing. This allows occupants to lower operable shades in the vision glazing zone at times when direct sunlight is reaching working surfaces. It also creates the opportunity for daylight glazing to allow indirect sunlight into the space without direct sunlight hitting working surfaces.

The majority of buildings require some form of operable shading devices to assist in visual comfort throughout the year. Discomfort glare can occur even with glazing that faces due north as the relative luminance of the sky on overcast days can be high enough to create discomfort glare in working environments. In urban environments it is also possible to have discomfort glare occur from reflections from surrounding buildings in any orientation.

When operable shading devices are required there are many options to choose from. Interior operable shades come in many variations. There are a number of very innovative internal and external shades that can help control visual comfort and optimize daylight.

Many buildings are starting to have greater amounts of automation with shading systems. This is important in office environments as occupants often are better at putting shades down than lifting them back up. The best option is to have automated shades with manual overrides. This will allow for shades to be automated to optimize the number of hours that daylight harvesting is possible while giving occupants the power to control their own visual comfort. With proper daylight sensors, artificial lighting layouts and zoned controls, buildings can save enormous amounts of energy, create a healthier environment for occupants with natural light and meet occupants relative visual comfort needs.

In addition to operable shading devices, there is a new technology known as electrochromic glazing that can innovatively control glare, optimize daylight harvesting and reduce maintenance costs. Electrochromic glazing is one variety of what is commonly called 'switchable glass' currently available on the market. This technology uses a small amount of voltage to darken the glass such that it can go from a visible light transmittance (VLT) of around 60 percent to less than 10 percent (e.g. 3 percent). In addition to lowering the VLT of the glass, which will help with glare control, it also reduces the solar heat gain coefficient that helps reduce cooling loads. The current technology takes a few minutes to switch from high levels of transparency to low levels, but it is likely to speed up as the technology advances.

This glass is more expensive when compared to other glazing, but when the costs of operable shading systems and high performance glazing are included, electrochromic glazing can be an economic alternative.

5.0 CONCLUSION

By understanding the potentials of discomfort glare and methods to control it the future for energy savings and visual comfort will be much brighter. Radiance gives designers the ability to predict the possibility for glare during the design process. Glare analysis should be undertaken early in the design process for any spaces with direct lines of sight to the upper portions of the sky. Glare analysis will assist in understanding how external fixed sunshades perform and where operable shading devices are needed. Translucent materials should be carefully considered if no operable shading devices are planned to be installed in front of them. Following these measures will help ensure building occupants can enjoy the benefits of daylight without visual discomfort.

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