Glare And Illuminance Uniformity as Components of Innovative Glazing Performance

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ABSTRACT
Four innovative glazing systems are assessed in terms of their potential to affect glare and daylight uniformity, as well as their effect on horizontal illuminance. The ability to control glare has energy as well as visual consequences and the systems are shown to be more effective than some types of conventional system. Although the innovative systems reduce average horizontal illuminance, this energy drawback can be offset by the energy benefits of improved uniformity.

INTRODUCTION

An assessment of spaces with innovative glazing needs to consider both energy and visual aspects. Although there are no data available on the subjective appraisal of such installations, current standards and recommendations oriented to the visual aspects of conventional lighting may be also applied to innovative glazing systems.

The energy and visual aspects of daylit spaces may be characterised by measurable physical parameters such as Horizontal Illuminance Levels, Uniformity, and Glare.

EXPERIMENTAL SET-UP

The work described in this paper is based on measurements carried out at the UK Building Research Establishment (BRE). The BRE test rooms consist of two identical south facing offices. One of these (used as a reference) has a conventionally glazed window, while the other (of the same dimensions) can be fitted with different innovative glazing systems. The rooms are 9m deep, 3m wide and 2.7m high. The results presented are indicative of likely performance in the sorts of deep spaces where alternative glazing systems are likely to find practical application.

Three commercially available glazing systems were tested: mirrored louvers, prismatic glazing and prismatic films. Light shelves were also evaluated, but only with respect to their impact on daylight uniformity. The 18-month experiment covered the full annual range of solar altitudes (Ref.1), during which the horizontal illuminance levels of both rooms were continuously recorded. During the spring, a series of spot luminance measurements were taken, in order to assess glare.

The data collected makes possible an evaluation of illuminance levels, uniformity and glare in both rooms.

ILLUMINANCE LEVELS

The amount of artificial light needed to carry out visual tasks in a space depends on the daylight available. An indication of the supplementary illuminance needed is the difference between the required task illuminance and the minimum illuminance available in the space from daylight.

$$Es1 = Ef - Emin \quad (1)$$

where:

Es1 = supplementary, functional illuminance from artificial light

Ef = functional illuminance required to perform the task, according to standards

Emin = minimum illuminance available in the space

The minimum illuminance (Emin) may be used as an indicator of the performance of a daylighting system.

In the course of the experiments, illuminance levels at six points on a horizontal working plane 0.7 m above the floor were continuously recorded. This data shows how

Table 1: Changes in minimum illuminance level
(time averaged values, referenced to conventional glazing = 100)

window glazing	Emin (%) (average)	Decrease (%)
Sky condition: overcast		
Conventional (reference)	100	--
Mirrored louvers	74	26
Light shelves	89	11
Prismatic glazing	62	38
Prismatic film	84	16
Sky condition: sunny winter day		
Conventional (reference)	100	--
Mirrored louvers	72	28
Light shelves	92	8
Prismatic glazing	53	47
Prismatic film	66	34
Sky condition: sunny autumn/spring day		
Conventional (reference)	100	--
Mirrored louvers	73	27
Light shelves	93	7
Prismatic glazing	91	9
Prismatic film	82	18
Sky condition: sunny summer day		
Conventional (reference)	100	--
Mirrored louvers	75	25
Light shelves	92	8
Prismatic glazing	67	33
Prismatic film	78	22

the innovative glazing systems affect the illuminance distribution and to what extent this would affect energy use.

Table 1 shows time averaged values of minimum illuminance levels in the room with different innovative glazing systems compared to a conventional window, whose value is shown as 100 for reference. All the innovative systems that were tested are internal; they simply redirect the light that would otherwise pass through the window. This process incurs losses and consequently the room with innovative glazing has lower average illuminance levels compared to the room with conventional glazing.

UNIFORMITY

Daylight entering through a window produces strong illuminance gradients, from high levels near the window to low levels at the back of the room (Ref.2). Users are generally more tolerant of the lack of uniformity for daylight than they are for artificial lighting. However, any improvement in uniformity is desirable. Various codes and recommendations (Ref. 3, 4) propose that the difference between minimum and maximum illuminance levels in a space be limited by:

$$\frac{J_{max}}{J_{min}} \leq 3 \qquad (2)$$

where
J_{min} = minimum daylight factor, and
J_{max} = maximum daylight factor

For a given external illuminance, equation (2) may be expressed in terms of a relationship between the maximum level of illuminance close to the window and a minimum level, generally near the opposite wall:

$$\frac{E_{max}}{E_{min}} \leq 3 \qquad (3)$$

It should be noted that this relationship (3) can be satisfied either by reducing the maximum illuminance or by increasing the minimum level. The choice depends on the control mechanism used to improve uniformity: e.g. a window shading device or supplementary electric lighting at the back of the room.

When shading devices are not available , and the condition expressed by Eq. (3) is not met, supplementary electric lighting will be needed of magnitude Es2, given by:

$$Es2 = \frac{E_{max} - E_{min}}{3} \qquad (4)$$

Table 2 shows the ratio of maximum to minimum illuminance for the four systems evaluated, relative to the conventional window, which is set at the borderline of uniformity to facilitate comparison. As can be seen, the innovative glazing systems improve uniformity except for sunny winter days when low angle sunlight penetrates deep into the rooms.

MINIMUM ILLUMINANCE VERSUS LIGHT UNIFORMITY

Supplementary artificial lighting needs can thus be set by two types of requirements, one based on functional illuminance and the other on lighting uniformity. Which of the two requirements is more important in terms of energy consumption?. The answer to this question depends on whether the space has a window shading device or not:

a) If the lighting uniformity is controlled merely by supplementary electric light, then the energy requirement from Es2 is larger than that needed to match functional illuminance, Es1.

b) If there is a shading device, the answer will depend on the extent to which the minimum illuminance (Emin) and the maximum illuminance (Emax) are altered.

GLARE

An ideal innovative glazing system would reduce glare without significantly reducing the light admitted into the interior.

Glare can be determined by means of weighted luminance measurements applying the Cornell formula for large-sources (Ref.6). The result is expressed as the Daylight Glare Index (DGI) with a corresponding semantic scale ranging from ”just imperceptible” to ”just intolerable”.

The DGI is given by the formula:

$$DGI = 10\log_{10} 0.478 \sum_{i=1}^{n} \frac{L_s^{1.6} \cdot \Omega^{0.8}}{L_b + 0.07 \cdot \omega_s^{0.5} \cdot L_w} \qquad (5)$$

- L_s is the average luminance of each glare source in the field of view [cd/m^2]
- L_b is the average luminance of the background excluding the glare source [cd/m^2]
- L_w is the average luminance of the window [cd/m^2]
- T_s is the solid angle of the source seen from the point of observation [sr]
- S is the solid angle subtended by the source, modified for the position of the light source with respect to the field of view and Guth's position index P[sr].
- n is the number of glare sources

If the whole window is treated as a single glare source then L_s is equal to L_w and n = 1.

The resulting values of glare are shown in Table 3, from which it is clear that the glare is greatly reduced by the innovative glazing systems.

It should be noted that these calculations are based on the average luminance of the window which is some 40 to 97% smaller than that of the conventional glazing (a result that coincides with bibliographical data (Ref.5)). On sunny days, at times when the sun is within the visible azimuth of the occupants, then some of the systems could, on occasion, provide extremely bright highlights which act as small area glare sources - luminances of up to 180 Kcd/m^2 were registered, a level that would be very uncomfortable for the occupants.

ENERGY IMPLICATIONS OF GLARE

In uncomfortable situations, users will act to reduce glare. The most effective means is by controlling the sky luminance that it is seen through the window. This can be achieved by a number of devices, such as curtains, venetian blinds, tinted glass, etc.

Any one of these methods reduces –to a greater or lesser extent– the quantity of light that enters the room and therefore affects horizontal illuminance levels. Alternatively using electric lighting to boost adaptation levels also uses energy. Thus, glare has energy implications.

What illuminance reductions might result from a conventional shading device?

For the case in which the shading device reduces the diffuse transmittance of the window by a uniform factor t (such as would be the case for the use of tinted glass) then the horizontal illuminance will be reduced by:

$$E'h = Eh \cdot \tau \qquad (6)$$

and the glare index will also be reduced by an amount D:

$$D = DGI_{(original)} - DGI'_{(window\ luminance\ reduced\ by\ factor\ \tau)} \qquad (7)$$

Substituting into equation 5 we find that the transmittance τ, necessary to reduce glare by a factor D is given by:

$$\tau := 10^{\left(\frac{-D}{6}\right)} \qquad (8)$$

Table 2: Changes in lighting uniformity (time-averaged values)

window glazing	Emax/Emin (average)	Improvement (%)
Sky condition: overcast		
Conventional (reference)	3	--
Mirrored louvers	2.65	13
Light shelves	2.5	20
Prismatic glazing	3.3	-10
Prismatic film	2.64	14
Sky condition: sunny winter day		
Conventional (reference)	3	--
Mirrored louvers	4.0	-26
Light shelves	3.4	-11
Prismatic glazing	8.4	-64
Prismatic film	4.5	-33
Sky condition: sunny autumn/spring day		
Conventional (reference)	3	--
Mirrored louvers	2.65	13
Light shelves	1.22	146
Prismatic glazing	2.82	6
Prismatic film	3.46	-13
Sky condition: sunny summer day		
Conventional (reference)	3	--
Mirrored louvers	1.46	105
Light shelves	1.49	100
Prismatic glazing	2.07	45
Prismatic film	2.15	40

Table 3: Change in Daylight Glare Index (time averages)

Sky condition: overcast day

window	glare index DGI	decrease DGI (average)	Subjective appreciation of glare
Conventional (reference)	24	--	just uncomfortable
Mirrored louvers	21	3	acceptable
Prismatic glazing	15	9	imperceptible
Prismatic film	19	5	perceptible

Sky condition: sunny day

window	glare index DGI	decrease DGI (average)	Subjective appreciation of glare
Conventional (reference)	26	--	uncomfortable
Mirrored louvers	24	2	just uncomfortable
Prismatic glazing	17	9	perceptible
Prismatic film	22	6	acceptable

Table 4 Changes in Daylight Glare Index

Sky condition: overcast day

window glazing	Decrease(D) in DGI (with respect to conventional glazing)	Reduction in minimum horizontal illuminance %	Transmittance (τ) of additional shading layerglazed required in conventional windows to match innovative glazing DGI, %	Reduction in minimum horizontal illuminance %
Mirrored louvers	3	26	32	68
Prismatic glazing	9	38	4	96
Prismatic film	5	16	15	85

Sky condition: sunny day

window glazing	Decrease(D) in DGI (with respect to conventional glazing)	Reduction in minimum horizontal illuminance %	Transmittance (τ) of additional shading layerglazed required in conventional windows to match innovative glazing DGI, %	Reduction in minimum horizontal illuminance %
Mirrored louvers	2	27	46	54
Prismatic glazing	9	9	3.8	96.2
Prismatic film	6	18	22	78

Table 4 was created using equation (8) and D values from Table 3. It can be seen that on an overcast day, a conventionally glazed window would require tinting with a transmission of 32% to reduce the DGI by the 3 points necessary to provide the same glare control performance as a mirrored louver. The 68% reduction in illuminance levels is considerably worse than for the louver system.

It can be seen that using tinting or another form of uniform shading is a grossly inefficient way of controlling glare and can lead to huge reductions in illuminance levels.

CONCLUSIONS

Despite the different technologies involved, the four innovative systems show several similarities - they reduce the average illuminance in the test room, they improve the uniformity in most conditions, and they provide a notable reduction in daylight glare.

The reduction in glare has important energy benefits since occupants would normally deal with glare by employing an alternative glare control device and / or by using additional electric lighting to improve adaptation - the ”blinds down, lights on” effect. The reduction in horizontal illuminance using the innovative systems is considerably less than with a alternative glare control system which provides a uniform reduction in transmission such as tinted glazing.

Several of the systems can produce small patches of high luminance which can act as small area glare sources. Some form of secondary glare control device may be needed (Ref.7).

The improvement in uniformity also has potential energy benefits since occupants are likely to use electric lighting to improve the illuminance balance within a daylit space, even if the horizontal illuminance levels are otherwise adequate. ●

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