224. Acceptability of screen reflections: lighting strategies for improving quality of the visual environment in the Classrooms of the Future

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Abstract
This article examines lighting strategies for the Classrooms of the Future where multi-tasking and a variety of display screens demand considerations beyond current guidance. Research to date has included a survey of visual environments in classrooms, surveys of users' opinions of lighting in classrooms and a review of existing guidance documents. The article concludes that a new system is needed for predicting the acceptability of reflections on display screens and identifies the constituents of this system.

Keywords: classroom, lighting, display screen, reflections

1. Introduction

In the UK the Department for Education and Skills (DfES) has launched two initiatives which aim to deliver inspiring and sustainable educational facilities. *Building Schools for the Future* was launched in 2004; under this programme, every secondary school in England will be renewed over a 10-15 year period. In 2003 the *Classrooms of the Future* programme was established to explore new ideas for designing educational environments for the 21st Century. One focus is toward taking advantage of developments in Information and Communication Technology (ICT), an evolution toward learner-centred, rather than teacher-centred, modes of learning. Increased use of ICT will expand the provision of Display Screen Equipment (DSE), the visual interface for ICT, and these self-illuminated objects demand different lighting considerations to traditional paper-based tasks.

In the Classrooms of the Future, a variety of DSE will be used – individual screens such as desktop and laptop computers and large, shared screens for whole-class audiences such as interactive whiteboards or plasma displays. Inappropriate lighting will cause disturbing reflections on DSE which will impair a learner's ability to perceive visual information and thus affects their performance.

Research at the University of Sheffield is investigating strategies for lighting in the Classrooms of the Future, including;

- Photometric surveys of the visual environment in classrooms.
- Using questionnaires to identify visual problems when using DSE in classrooms.
- A review of current lighting guidance concerning DSE use in classrooms and its limitations.
- Laboratory tests of reflections on DSE.

Current experimental work is investigating the interaction between lighting, display screen properties and user responses (i.e. acceptance and performance) based on the nature of DSE uses in schools. The findings will be used to develop a revised system for prescribing lighting recommendations based on reflection properties of display screens which is to be incorporated in the 2009 revision of Society of Light & Lighting (SLL) Lighting Guide 5.

2. The visual environment in classrooms

2.1 Survey of luminance distribution

A wide variation of room surface luminances and sizes will impair readability of DSE. The objects expected to cause problems of disturbing reflections are small surfaces of high luminance, such as electric light sources and windows, which are expected to cause distinct and distracting reflections, and large surfaces of which the reflections can wash out the entire screen.

A survey of the visual environment in classrooms was carried out to identify the expected sources of reflection, and this was done under conditions of electric lighting, daylighting, and the two combined. Luminance levels were surveyed using a luminance meter and luminance mapping using WebHDR, a web-based programme that converts exposure-bracketed digital photographs into one image of high-dynamic range with photometric information [1]. Figure 1 shows surfaces that will be seen reflected on DSE for users in various positions in classrooms and maximum luminance.

Under daylight, the luminance of the sky seen through windows reached 1,000 cd/m² and is predicted to be as high as 10,000 cd/m², depending on the sky condition. Daylight coming through windows causes bright patches on some surfaces in its path, especially glossy ones. The survey found the luminance of these patches is up to 400 cd/m². When electric lighting is on, luminaires can be the brightest objects in classroom with luminances approaching 2,000 cd/m². When indirect lighting is used, bright patches on the ceiling can reach 1,000 cd/m².

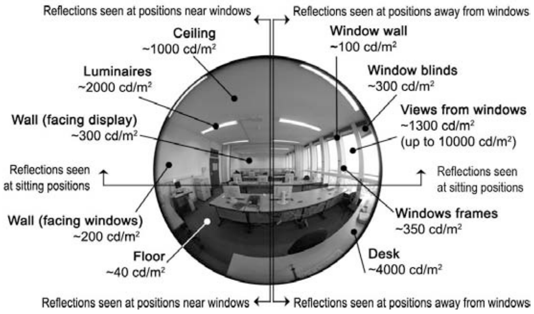

Fig 1. Surfaces reflected on display screens for users in various positions in classrooms and estimated maximum luminance.

The contrast between the luminance of these bright surfaces and the much lower luminance of adjacent surfaces in classrooms was found to be up to 30:1. This is the scene facing the display screens in classrooms, causing reflections that draw attention from the intended visual tasks.

The reflected images depend on the geometry between the user, the display screen, and the bright source. For screens usually viewed by a single user, such as individual PCs, it is simple to control this geometry and avoid distracting reflections from appearing on the screen, e.g. by tilting or rotating the screen. However, it is difficult to take such action for a screen viewed from various locations by the whole-class, such as interactive whiteboards, and avoiding reflection can be difficult. A large screen means reflected scene will cover larger and wider ranges of surfaces in classrooms.

2.2 Problems with reflections in classrooms

Visual tasks on self-luminous display screen are fundamentally different from non-self-luminous visual tasks such as paper or traditional whiteboards. For paper-based tasks, task contrast is constant, visual performance will increase with ambient illumination up to the point of diminishing returns, the plateau in the RVP model [2]. For display screens, ambient illumination produces wash-out reflections which reduce apparent screen contrast; and distinct reflections draw attention away from displayed information.

The simplest solution of reflections is to limit light falling on to DSE which is typically done by limiting luminance in the geometry that can be seen from DSE or lower illumination level when using DSE by dimming or switching. However this is not applicable the Classroom of the Future where a variety of tasks will be carried out simultaneously – individual PCs, paper-based tasks, small group discussions and large group discussions using the interactive whiteboard – and it will not be possible to use a simple solution such as dimming to create lighting condition suitable for all of these tasks.

It is likely that typical brightly lit classrooms, that accommodate paper-based tasks very well, will run the risk of reflection problems on DSE, e.g. wash-out screen, distracting reflections. The prevalence of these problems is confirmed by surveys of ICT classroom users.

2.3 Surveys of classroom users

To identify problems with lighting in classrooms using DSE, two questionnaires are being used to survey ICT classroom users, one targeted at teachers and the other at pupils. The questionnaires include questions about the work under taken, the learning methods used, and the visual environment.

Responses have been received from six schools to date. These identify problems when carrying out visual tasks on display screens but few problems with paper-based tasks. Initial responses from teachers (n=24) reveal visual problems when using interactive whiteboards. Initial responses from students (n=134) identify problems of legibility caused by veiling reflections on the interactive whiteboard as well as on individual PC screens. Figure 2 and 3 shows responses in terms of readability in ICT classrooms from the questionnaires to teacher and pupil.

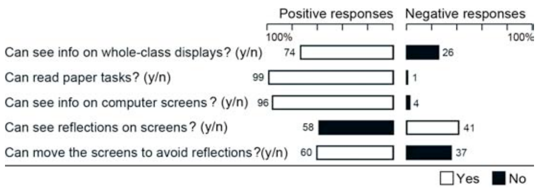

Fig 2. Responses from pupils in terms of readability of visual tasks in classrooms.

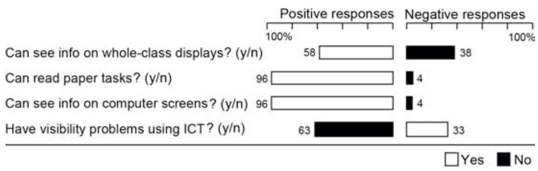

Fig 3. Responses from teachers in terms of readability of visual tasks in classrooms.

The survey results draw attention to the interactive whiteboard. This is the standard apparatus for whole-class displays in ICT classrooms and the apparatus with most reports of visual problems by both pupils (26%) and teachers (38%). This may be because its position is fixed and it is viewed from various positions in a classroom, giving limited options for adjustment to avoid reflections, unlike a PC screen. Responses from pupils show that there were significant association between ability to adjust a display screen and the report of reflections ($Chi^2=45$, $p<0.001$).

2.4 Reflection components of DSE

Screen reflections can be characterised by three types of reflection component: diffuse, specular and haze [3]. Variations in display technology and surface treatments mean different screens produce these reflection components in different proportions and thus reflect the ambient lighting in different patterns.

Diffuse (Lambertian) reflection scatters light in all direction of the hemisphere above the surface. Diffuse reflection component will be seen as uniform bright area across the display, slightly brighter towards the glare source and darker towards the edge of the display. (Figure 4) Diffuse reflection is dependent on the illuminance on the display. Diffuse reflection component does not cause distracting images but uniform reflection that washes out the contrast between the images and the background.
Specular reflection produces distinct reflection in the mirrored direction which can easily draw attention from intended tasks if they are bright enough. Specular reflection component is clearly visible on screens with smooth surfaces such as CRTs (Cathode Ray Tube) or glossy LCDs (Liquid Crystal Display). The luminance of the specular reflection depends on the luminance of the glare source.
Haze reflection is somewhere between specular and diffuse reflection. Haze reflection component causes blurry reflection of which the luminance peaks in the specular direction. Haze reflection occurs by intrinsic optical properties of the display (e.g. electrodes in LCDs) or anti-glare treatments to the display surface. These treatments help scatter or blur the reflections thus reducing peak luminance and clarity of reflected images. However, the anti-glare treatments also reduce the contrast and the clarity of the screen.

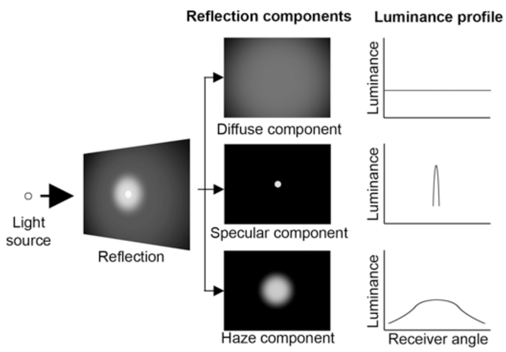

Fig 4. Three reflection components and their luminance profiles observed from various angles

3. Existing lighting guidance

ICT is widely accepted as a key to future education and DSE will become standard in future classrooms. Nevertheless it is questionable whether the visual environment classrooms can satisfy DSE tasks while maintaining performance of other visual tasks, based on the existing lighting guidance. The design of lighting for Classrooms of the Future involves lighting guidance in two categories: lighting guidance for teaching environments and lighting guidance for DSE environments.

3.1 Lighting guidance for teaching environments

The main reason that current classroom guidance may not ensure visibility at DSE is that these guidance are not adequately updated so they cannot cover new methods of teaching and new visual tasks in classrooms. Also display technology is changing rapidly. So the guidance can be easily obsolete.
For example, in the U.K, the key guidance for classrooms are Building Bulletin 90: Lighting Design for School, [4], and Lighting Guide 5: The Visual Environment in Lecture, Teaching and Conference rooms [5]. BB90 was revised in 1999 and LG5 in 1991 with minor adjustment of some data in 2003 [6] for compliance with European Standard EN 12464-1 [7], so these documents are not up to date with DSE technology in classrooms. BB90 and LG5 assume that PC use is confined to special computer suites; PCs are not common in classrooms and used for relatively short period. Insufficient DSE recommendations in classroom guidance may lead to two extreme lighting solutions. At one end, classroom lighting is designed without taking account of DSE uses which risks reflection problems. At the other end, when there are some DSE in classrooms, this lighting guidance will refer to lighting guidance for DSE which is designed for office environment, based on different DSE applications. Unfavourable consequences include specifications for extremely low cut-off angles in luminaires, causing gloomy, unpleasant environments.
Furthermore, existing guidance was written to suit old-style visual aids used in formal or teacher-led instruction where attention in a classroom is directed to only the information on the screen. Any visibility or reflection problem at the screen can be fixed by simply dimming or switching off the lighting. However, in the Classrooms of the Future, DSE are used to support interactive learning so apart from visual tasks at DSE the lighting also needs to cater for interaction between individuals and the variety of visual tasks taking place simultaneously.
In summary, lighting guidance for classrooms lacks detailed and updated recommendations for display screens that can ensure readability, comfort and performance using the apparatus. There are some recent guidance published in the U.K. giving some lighting recommendations with regards to DSE uses, such as BB 95: Schools for the future: Design for learning communities [8] Standard Specification, layouts an dimensions 4: Lighting systems in schools [9]. Nevertheless, these guidance only give general rules and concepts and still lack specific values or systems that can ensure the quality of visual performance in classrooms.

3.2 Lighting guidance for DSE environments

Figure 5 shows system of DSE lighting guidance in the UK. Health and Safety DSE Regulations ensure the quality of visual environment with DSE. Taking the regulations into account, there are two categories of DSE guidance. The first category is the lighting guidance providing recommendations and requirements for visual environment with DSE. Guidance in this category are British Standards-- BS EN 12464-1 [4], BS EN 9241-6 [10], Lighting Guide 3 [11,12] issued by SLL/CIBSE in 1996 with addendum in 2001.

Lighting guide 3 was included in Lighting Guide 7: Office Lighting [13]. To avoid reflection problems, these guidance prescribes limits for the luminance of luminaires according to the classification of the DSE screens used in the room. According to BS EN 12464-1, the limits of luminaire luminance are up to 1000 cd/m^2 for screen categories I and II and up to 200 cd/m2 for screen category III. LG3 and LG7 expand the limits for positive polarity screens to 1500 cd/m^2 for screen categories I and II and up to 500 cd/m^2 for screen category III.

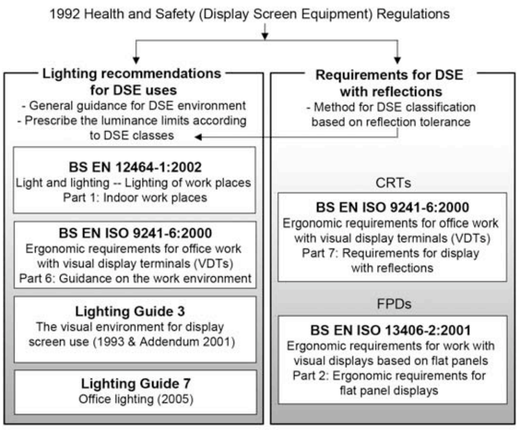

Fig 5. System of DSE lighting guidance in the UK.

The second category is the requirements for DSE. Working in conjunction with the lighting guidance, these guidance provides method to determine DSE classification based on reflection tolerance. Compliance with each of the three DSE classes is determined from DSE ability to maintain a certain image quality in the reference condition of each class, representing luminance levels of the source of reflections. Guidance in this category are BS EN ISO 9241-7 [14] for CRTs and BS EN ISO 13406-2 [15] for FPDs (Flat Panel Display) which have different optical properties to CRTs.

The current standards for DSE image quality are based on the principle of contrast threshold – the minimum contrast that visual system requires for detection or recognition [16]. That is:

– To maintain the contrast (or luminance ratio) of the displayed images in presence of reflections above a certain level – the threshold contrast needed for adequate display legibility. Two British Standards gave different ratios for different display technologies.

CRTs: $$\frac{L_{HS}+L_D+L_S}{L_{LS}+L_D+L_S} \geq 3$$

FPDs: $$\frac{L_{HS}+L_D+L_S}{L_{LS}+L_D+L_S} \geq 1+10\times\left(L_{LS}+L_D+L_S\right)^{-0.55}$$

– To keep the contrast (or luminance ratio) of the reflected images below a certain level – the threshold contrast defining visibility or acceptability. Reflections with contrast below this value are functionally invisible or acceptable to observers [17]. Different ratios are used for different display polarities but both ratios apply for all display technologies.

Positive polarity: $$\frac{L_{HS}+L_D+L_S}{L_{HS}+L_D} \leq 1.25$$

Negative polarity:
$$\frac{L_{LS}+L_D+L_S}{L_{LS}+L_D} \leq 1.2+\frac{1}{15}\times\frac{L_{HS}+L_D}{L_{LS}+L_D}$$

L_{HS}= Luminance of display in high state (brighter colour)
L_{LS} =Luminance of display in low state (darker colour)
L_D= Luminance of non-specular reflection
L_S = Luminance of specular reflection

The contrast of displayed images and the contrast of unwanted reflections are dependent on both display (luminance of display images and background, reflectance characteristics – specular and non-specular components) and lighting parameters (illuminance and luminance of the reflected sources). BS EN ISO 9241-7 and BS EN ISO 13406-2 measure DSE to determine display parameters and use the contrasts equations to predict legibility of the displayed images and acceptability of screen reflections.

Contrast equations are derived from experiments carried out in the late 1980s with CRT screens [18]. Two test methods were used to identify reflection disturbance threshold: luminance adjustment and subjective rating. It was found that the ratio between image contrast and reflection contrast of all tested screen is fixed at around 3, at the disturbance threshold. This number was used to identify luminaire luminance at the threshold of each screen and identify two standard luminances which divide display screens into two groups: the screens that can tolerate reflected luminance up to 200 cd/m^2 and the screen that can tolerate reflected luminance up to 1000 cd/m^2. Two key luminance levels are used in BS EN 12464-1 to specify limits of luminaire luminance.

3.3 Problems with DSE guidance

There is reason to suspect these luminaire luminance limits are incorrect - much higher luminaire luminances are suggested to be tolerable [19] and this may be due to progressive improvements in screen technology, such as increased brightness, contrast ratio and anti-reflection treatment. One problem is that much existing guidance is based on research carried out with CRT screens whereas LCDs account for the majority share of PC monitor market. LCD screens have different characteristics to CRT screens and studies reveal differences in visual performance and subjective rating. Therefore there is a need to review and update the thresholds used to define the screen categories, and/or to revise the limits of luminaire luminance in these categories.

Preliminary screen reflectance tests with a range of CRT and LCD displays were carried out in the laboratory at Zumtobel Lighting Ltd. by one of the authors (TR). These tests followed the measurement method in BS EN 9241-7 and

13406-2. These data were used to predict the maximum luminance of the reflected source (L_{max}) to which a screen can be exposed without causing disturbing reflections, and this was done using the equations [19] as adapted from those in BS EN 9241-7 and 13406-2 [14,15]. The results of these preliminary tests reveal two faults in the existing classification system.

Firstly, the calculated L_{max} of many LCD screens are much higher (up to 7000 cd/m^2) than the luminaire luminance limits suggested in LG3 and LG7. (e.g. 1500 cd/m^2 for type I, positive polarity) This supports the earlier study [19] that proposed higher luminance limits.

Secondly, some glossy screens with high contrast can pass the compliance test and have high calculated L_{max} while observation shows that reflections are apparent and distracting, particularly for negative polarity. This draws attention to the reflected image contrast equation that, for negative polarity, the threshold contrast of reflected images depends on the contrast of displayed images. This means that for modern displays with very high contrast, the contrast of reflected images can be very high according to the equation, which may be in conflict with actual user acceptability. For some screens, the current system for prescribing luminaire luminance limits may not be able to predict user acceptability.

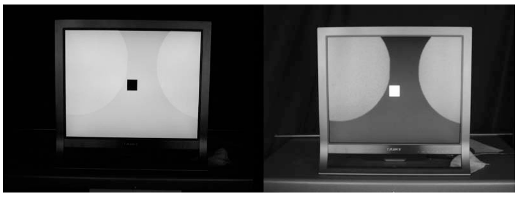

Fig 6. A type I glossy screen with calculated high L_{max} but still presents distracting reflections.

In an attempt to better predict glare acceptability than does luminance, the American National Standard Practice for Office Lighting [20] now uses luminous intensity as a standard to control disturbing reflections from direct lighting on DSE. This is based on recent research [21] that rating of acceptability of reflections was better predicted by luminous intensity than by luminance.

The current UK system of luminaire luminance limits is based on the photometric properties of the displays. Studies have shown that the current measurement method of BS EN 9241-7 and 13406-2 cannot identify the haze component of reflection but include it with diffuse component and call them non-specular reflection [3,22]. Failing to characterise screen reflection properties leads to inaccurate prediction of image quality of the screen in presence of source of reflections. A high proportion of variance in observers' responses to disturbing reflections can be explained by some parameters of blur reflections which are caused by the haze component [23]. The haze component is common in modern screens, such as LCDs and interactive whiteboards, as well as any screen with anti-glare surface treatment – all of them can be found in ICT classrooms.

4. Revised system for predicting acceptability of screen reflections

In order to improve the quality of the visual environment in classrooms, current lighting guidance need to:

- Accommodate a variety of visual tasks in classrooms with comfort and performance: non-self-luminous and self-luminous tasks.
- Take account of rapid development of display technologies, a variety of technologies and reflection properties in classrooms.

In the existing system of guidance, lighting for rooms using DSE is restricted by the quality of display screens that will be used. This article has discussed inadequacies of lighting guidance due to changes in DSE. DSE technology changes rapidly, whereas the lit environment does not. To allow for developments in DSE technology, it would be pragmatic to specify minimum qualities of display screens to suit the lit environment – as DSE technology improves, such specification would remain valid. The new systems will be based on the interaction between display parameters, lighting parameters and user responses.

Display parameters

- Brightness: luminances of displayed images and background
- Contrast: luminance ratio of displayed images
- Reflection parameters to identify diffuse, specular and haze reflections.

Lighting parameters

- Brightness: luminance and illuminance
- Sizes of reflected sources

User responses

- Acceptability of reflections
- Performance: speed of reading

Experimental work has been set up to identify the key display parameter(s) that affect user acceptance and performance in presence of display reflections and the weight of these parameter(s) in the relationship. The relationship will be combined into a new model to predict users responses to lighting and reflections based on properties of the display.

The model will be compared to the current predictive equations that determine acceptability and legibility in British Standards. The outcome will determine the revision of reflection compliance equations or luminaire limiting values in current lighting guidance.

The acceptability of screen reflections will be tested using the adjustment method and the category rating method, as used in previous work [18,23]. The use of two psychophysical test methods, each with their own inherent bias enables more robust conclusions to be drawn.

- Adjustment method: the subject adjusts the luminance of the reflected light source to identify the disturbance threshold.
- Category rating: the subject rates a reflection on the display screen along scales ranging from 'not at all' to 'extremely' disturbing. This is repeated at a range of luminances to enable interpolation of the disturbance threshold luminance.

The tests use a range of screen types, chosen to represent those commonly found in ICT classrooms. It was predicted that the LCD screen with anti-glare coating, having high screen luminance and high haze reflectance, will tolerate the highest luminaire luminance before reflections are disturbing; the CRT screen with no surface treatment is predicted to tolerate only the lowest luminance before reflections become disturbing.
These psychophysical tests identify the perceptual effects; a reading task is used to provide an objective measure of how screen type and light source luminance affect task performance.

5. Conclusion

This article has examined lighting strategies for Classrooms of the Future where multi-tasking and a variety of display screens will demand considerations beyond current guidance. Research to date has included a survey of visual environments in classrooms, surveys of users' opinions of lighting in classrooms and a review of existing guidance documents. This research has shown that current guidance is insufficient to meet these needs and that a new system is needed for predicting the acceptability of reflections on display screens.
The proposed framework for lighting guidance will provide recommendations for choosing displays screens by their photometric qualities to suit the lighting conditions in classrooms, rather than vice versa as is the current situation. The results will feed into the 2009 revision of the SLL Lighting Guide 5. [5,6]

6. Acknowledgements

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