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LIGHTING FOR THE CLASSROOMS OF THE FUTURE.
ELECTRONIC CLASSROOMS: A NEW CHALLENGE FOR SCHOOL LIGHTING GUIDANCE

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ABSTRACTS

This article examines lighting strategies for the proposed Classrooms of the Future where the learning activities will be learner-lead and will use a greater range of display screens than the traditional teacher-lead mode of learning. Hence, in these classrooms a variety of different tasks will be carried out simultaneously, and this places new demands on the design and control of lighting. A critical issue is the occurrence of disturbing reflections on display screens, in particular the interactive whiteboard which is viewed from many locations. Research is being carried out to establish a new method for specifying lighting in future classrooms which can accommodate advances in display screen technology. This paper was presented at Balkan Light 2008 Conference.

Keywords: classroom, lighting, display screen, interactive whiteboard, reflections

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1. INTRODUCTION

The introduction of computers to the workplace has transformed the visual environment of offices since the 1970s. In the 21st Century the same transformation is taking place in schools, and this makes current lighting guidance for classrooms inadequate. Lighting for the Classrooms of the Future, a research project at the University of Sheffield, School of Architecture, is exploring strategies for lighting guidance for classrooms where the use of display screen equipment will be greatly increased.

The Classrooms of the Future programme was initiated by the UK Department for Children, Schools and Families (DCSF) to experiment with the new ideas for designing educational environments for the 21st Century, taking advantage of developments in Information and Communication Technology (ICT) [1]. Increased use of ICT implies an expansion in the provision of Display Screen Equipment (DSE), the visual interface of ICT, and these self-illuminated objects demand different lighting considerations to traditional paper-based tasks. This research uses Classrooms of the Future as a model to study how display technologies affect demands of lighting in future classrooms. Classrooms of the Future programme emphasises learner-centred mode of learning in which students are self-paced and use individual PCs, paper-based tasks, group discussions and large interactive display screens for whole-class activities. These learner-centred modes of study mean that different tasks will be carried out simultaneously, each having their own criteria for the amount and spatial distribution of lighting, and hence conflict can arise in lighting requirements.

This paper discusses the issues that question the adequacy of current lighting guidance for classrooms with DSE, including: the changing nature of visual tasks in classrooms, visual problems when using DSE in classrooms, and problems with current lighting guidance in classrooms. The findings lead toward experimental work being carried out to test the acceptability of reflections on DSE used in classrooms, and which hence provide a basis for a revised system of prescribing lighting recommendations based on the properties of display screens. The results will feed into the current revision of Society of Light and Lighting (SLL) Lighting Guide 5: The visual environment in lecture, teaching and conference rooms.

2. VISUAL TASKS IN THE CLASSROOMS OF THE FUTURE

In the Classrooms of the Future, there will be both self-luminous and non-self-luminous tasks. Visual tasks on self-luminous display screen are fundamentally different from non-self-luminous visual tasks such as paper or traditional whiteboards. For non-self-luminous 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 self-luminous- tasks, ambient illumination produces reflections which affect visual performance in three aspects. Wash-out reflections reduce legibility of screen characters, causing impairment of viewing which at the extreme point the contents of the screen become unrecognisable. Distinct reflections draw attention away from intended tasks. Finally, the observer eyes may accommodate toward the apparently distant reflected image rather than on the screen surface. The degree of these reflections, which determines the visual performance and the acceptability of screen reflection, is dependent on the relationship between lighting parameters, display screen parameters and the geometry between observer, display screen and light source.

Lighting parameters include:

- –Luminance of bright sources.
- –Luminance contrast between the bright source and surrounding area, and the distinctness of their edges.
- –Illumination on display screen.

Display screen parameters include:

- –Display luminance: generated from mechanism in the self-luminous display; or reflected from the displays that use projection or reflective technology.
- –Display contrast: determined from the luminance of foreground and luminance of background.
- –Display polarity: designated by types of applications and software used.
- –Display reflection properties: characterized by three components of reflections – diffuse, specular and haze reflections.

The simplest solution to avoid reflections is to limit luminance in the geometry that can be seen from DSE, or alternatively to lower the general illumination level when using DSE by dimming or switching. However this is not applicable to ICT classrooms where a variety of individual and group tasks are being carried out at the same time, and it will not be possible to use a simple solution such as dimming to create lighting condition suitable for all of these tasks. Appropriate lighting for ICT classrooms is therefore a compromise between providing sufficient light for non-self-luminous visual tasks and controlling the amount of light on display screens to avoid disturbing reflections. The complication is in the Classrooms of the Future not only non-self-luminous visual tasks and visual tasks on display screens are being carried out simultaneously, a variety of display screens are used in the same environment. The lighting needs to cater for the variety of display technologies in classrooms and the variety of geometry they will be used. Table 1 shows the properties of a sample of display screen equipment as used in classrooms.

Table 1. Properties of display screen found in ICT classrooms

Display screen equipment	**Maximum luminance (cd/m^2)**	**Contrast (Luminance ratio)**	**Major reflection component**	**Horizontal viewing angle range**	
				Likely used in classrooms	**Specified by manufacturers**
CRT monitor	150	700	Specular	±40	±90
LCD monitor (with Anti-glare)	300	200	Haze	±40	±70
LCD monitor (with Anti-reflection)	400	500	Specular	±40	±85
Projection screen with LCD projector	320	500	Diffuse	±60	±50
Front-projection interactive whiteboard	300	2000	Diffuse	±60	±85
Flat-screen-overlay interactive whiteboard (Plasma screen with interactive overlay)	425	2000	Haze	±60	±80

DSE in classrooms can be categorized into two groups according to how they are viewed. The first category includes individual DSE used or viewed by only one or two users, such as laptop or desktop monitors, thus having a limited viewing geometry. The second category includes shared DSE – a large screen connected to a computer and viewed by multiple users such as small groups or whole-class audiences. Examples of DSE in this category are interactive whiteboards, projection screens, and large LCD and plasma screens. These screens are viewed from various locations within a classroom. (Fig. 1) Reflections on DSE depend on the geometry between the user, the screen, and bright objects in the reflected field of view. For DSE in the first category 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 and avoid reflection for DSE in the second category. In addition, a large screen means reflected scene will cover larger and wider ranges of surfaces in classrooms.

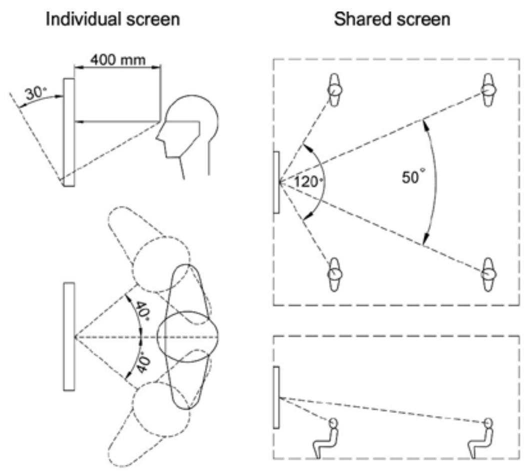

Fig.1. Viewing geometry for individual user and a shared screen for whole-class users.

3. SURVEYS OF CLASSROOMS USERS: DSE USES IN CLASSROOMS AND VISUAL PROBLEMS

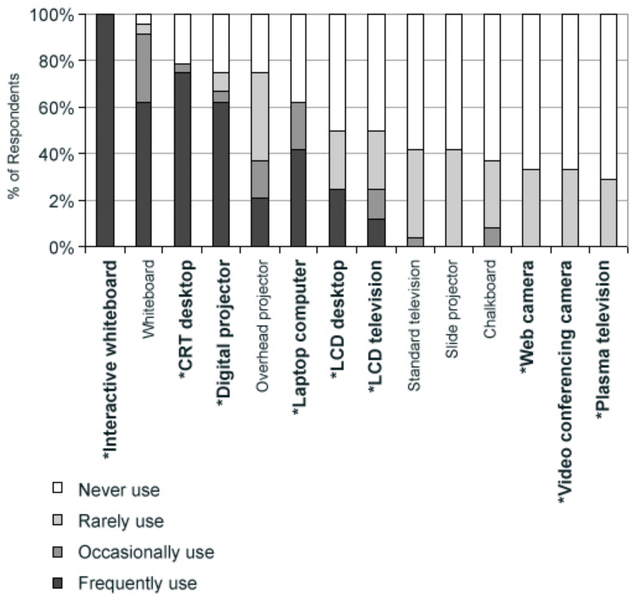

Figure 2. The frequency of usage of ICT and other teaching equipment reported by the respondents.

Surveys of classroom users were carried out to investigate the variety of visual tasks that take place in ICT classrooms and problems experienced with lighting in these classrooms when using DSE. One survey targeted teachers and the other targeted pupils. Questionnaires were sent to 10 schools in Sheffield and responses have been received from six schools to date. The results shows that DSE are becoming more common than traditional visual aids and that there are a variety of display screens being used in classrooms. The frequency of usage of ICT is shown in Fig. 2. The interactive whiteboard is the most common teaching apparatus. Other display screens are also common – the CRT (Cathode Ray Tube) or LCD (Liquid Crystal Display) and projection screens used with digital projectors. The surveys revealed problems when carrying out visual tasks on DSE 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. Fig. 3 shows responses in terms of readability in ICT classrooms from the questionnaires to teachers and pupils. The survey results draw attention to the interactive whiteboard. This is the standard apparatus for whole-class displays in ICT classrooms and the apparatus which receives the 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 PC screens. Responses from pupils show that there were significant association between ability to adjust a display screen and the report of reflections ($Chi^2=45$, $p<0.001$).

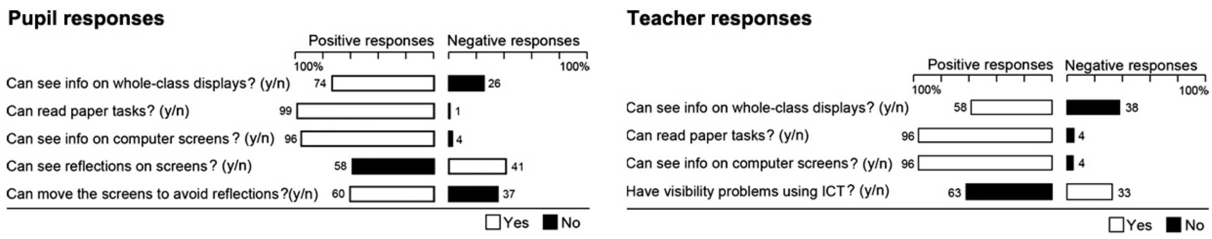

Fig.3. Responses from pupils and teachers in terms of readability of visual tasks in classrooms.

4. REFLECTIONS ON DISPLAY SCREENS

Display reflections can be characterised by three types of reflection component: diffuse, specular and haze [3]. (Fig. 4) 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. (Table 1)

- 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. Diffuse reflection component does not cause distracting images but uniform reflection that washes out the contrast between the images and the background. Diffuse reflection is dependent on the illuminance on the display.
- Specular reflection produces a 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 combines the characteristics of specular and diffuse reflection. Haze reflection component causes blurry reflection of which the luminance peaks in the specular direction. It occurs due to intrinsic optical properties of the display (e.g. electrodes in LCDs) or anti-glare treatments to the display surface.
- Anti-glare (AG) treatments use mechanical or chemical etching on the display surface to scatter or blur the reflections thus reducing peak luminance and clarity of reflected images – reducing specular component but increasing haze component of reflections. The AG treatments also reduce the screen contrast and clarity.
- Anti-reflection (AR) treatments use optical treatment to reduce reflection. The coatings match the index of refraction of air so eliminates reflection and improve the contrast of the images. However AR capabilities change with incident angle so performance is reduced if the light rays are not normal to the surface. Glossy displays use AR treatment to reduce

reflection while maintaining contrast of the displays however when viewing direction are not normal (as in the whole-class display), reflections can still be apparent for some viewers.

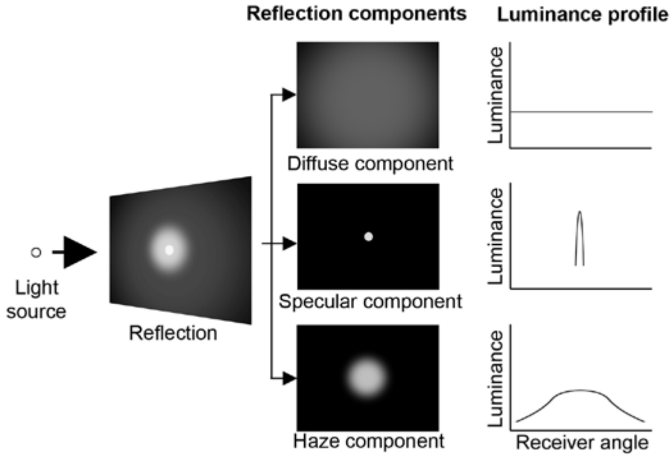

Fig. 4. Three reflection components and their luminance profile observed from various angles.

5. 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.

5.1 Lighting guidance for teaching environments

The main reason that current classrooms guidance may not ensure visibility at DSE is that these guidance are not adequately updated while display technology is changing rapidly. So the guidance cannot cover new methods of teaching and new visual tasks in classrooms. For example, in the U.K, the key guidance documents 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 adjacent to the screen. 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. There are some recent guidance published in the U.K. giving some lighting recommendations with regards to DSE uses, such as Building Bulletin 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.

5.2 Lighting guidance for DSE environments

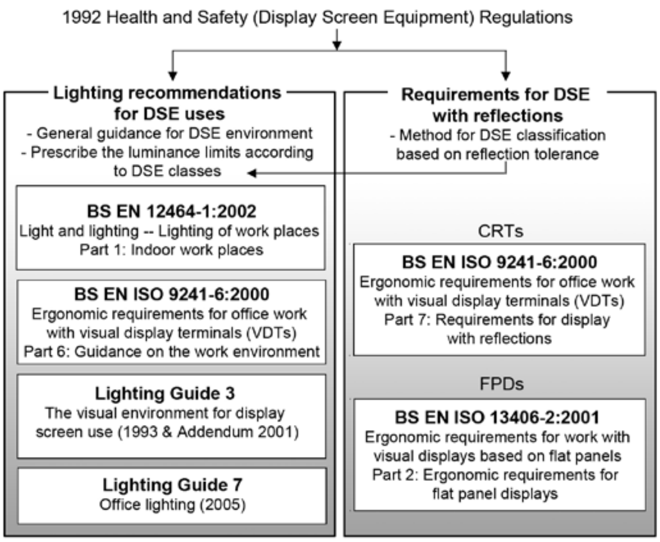

Figure 5. Systems of DSE lighting guidance in the UK.

Fig. 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 [9], 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 prescribe 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.

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 for CRTs and BS EN ISO 13406-2 for FPDs (Flat Panel Display) which have different optical properties to CRTs [14,15].

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. 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: $$\frac{L_{HS}+L_D+L_S}{L_{LS}+L_D+L_S} \geq 3 \qquad (1)$$

  FPDs: $$\frac{L_{HS}+L_D+L_S}{L_{LS}+L_D+L_S} \geq 1+10\times\left(L_{LS}+L_D+L_S\right)^{-0.55} \qquad (2)$$

- 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. Different ratios are used for different display polarities but both ratios apply for all display technologies.

  Positive polarity: $$\frac{L_{HS}+L_D+L_S}{L_{HS}+L_D} \leq 1.25 \qquad (3)$$

  Negative polarity: $$\frac{L_{LS}+L_D+L_S}{L_{LS}+L_D} \leq 1.2+\frac{1}{15}\times\frac{L_{HS}+L_D}{L_{LS}+L_D} \qquad (4)$$

  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 [16]. 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 screens 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.

5.3 Problems with DSE guidance

There is reason to suspect these luminaire luminance limits are incorrect - much higher luminaire luminances are suggested to be tolerable [17] 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 LCD screens 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 as adapted from those in BS EN 9241-7 and 13406-2. 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 that proposed higher luminance limits [17]. 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. (Fig. 7.) 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. In an attempt to better predict glare acceptability than does luminance, the American National Standard Practice for Office Lighting [18] now uses luminous intensity as a standard to control disturbing reflections from direct lighting on DSE. This is based on recent research [19] that rating of acceptability of reflections was better predicted by luminous intensity than by luminance.

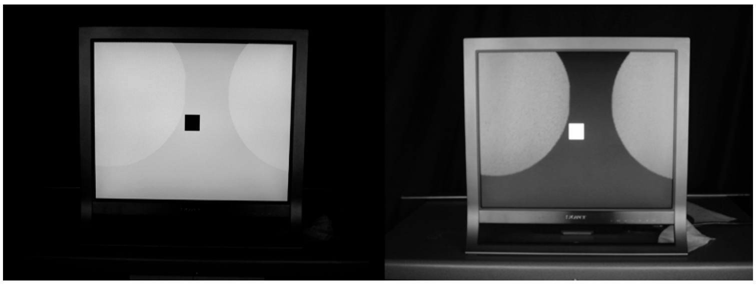

Fig. 7. A type I glossy screen with calculated high L_{max} but still presents distracting reflections.

In addition, 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 [3,20]. 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 [21] which are caused by the haze component. 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.

6. REVISED SYSTEM FOR PREDICTING ACCEPTABILITY OF SCREEN REFLECTIONS

In order to improve the quality of the visual environment in classrooms, current lighting guidance needs to (a.) accommodate a variety of visual tasks in classrooms with comfort and enabling performance: these may be non-self-luminous and self-luminous tasks and (b.) take account of rapid developments in display technology. 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 (acceptability of reflection and performance). (Fig. 8.)

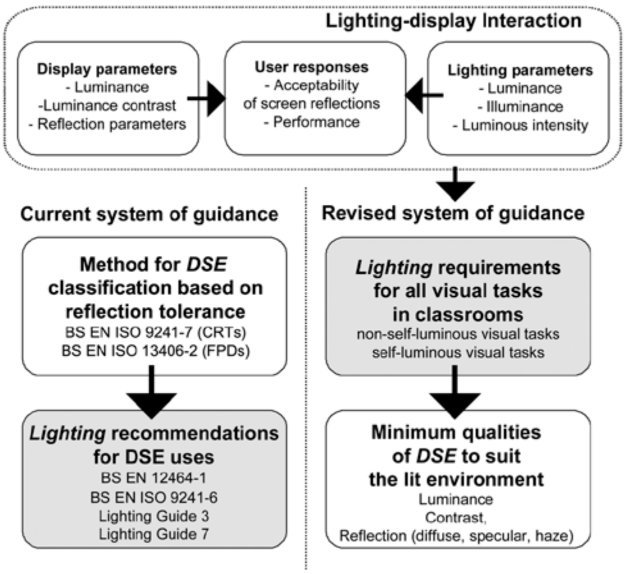

Figure 8. Current and revised systems of lighting guidance for DSE uses based on lighting-display-user response interaction.

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 works [16,21].

The use of two psychophysical test methods, each with their own inherent bias enables more robust conclusions to be drawn. 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.

7. CONCLUSION

This article has examined lighting strategies for Classrooms of the Future where multiple, self-paced tasks, 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.

8. ACKNOWLEDGEMENTS

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REFERENCES

1. DfES (2003). Classrooms of the Future. London, Department for Education and Skills.
2. Rea, M.S. (1991). Relative visual performance: A basis application. Lighting Research and Technology, 23(3): p. 135-144.
3. Kelly, E.F., Jones, G.R., Germer, T.A. (1998). Display reflectance model based on the BRDF. Display, 19(1): p. 27-34.
4. Architects and Building Branch. (1999). Building Bulletin 90 Lighting Design for Schools. London, Department for Education and Employment.
5. CIBSE, (1991). Lighting Guide 5 The visual environment in lecture, teaching and conference rooms. London, CIBSE.
6. SLL, (2003). Addendum to CIBSE Lighting Guide 5 The visual environment in lecture, teaching and conference rooms. London, Society of Light and Lighting.

7. BSI, (2002) BS EN 12464-1:2002 Light and lighting. Lighting of workplaces -- Part 1: Indoor workplaces. London, BSI.
8. School and Building Design Unit, (2002). Building Bulletin 95 Schools for the Future Designs for Learning Communities. London, The Stationery Office.
9. DCSF, (2007). Standard Specifications, Layouts and Dimensions 4: Lighting systems in schools. London, Department for Children, Schools and Families.
10. BSI, (2000). BS EN ISO 9241-6:1998 Ergonomic requirements for office work with visual display terminals (VDTs) – Part 7: Guidance on the work environment. London, BSI.
11. CIBSE, (1996). Lighting Guide 3 The visual environment for display screen use. London, CIBSE.
12. SLL (2001). Addendum to CIBSE Lighting Guide 3 The visual environment for display screen use. London, SLL.
13. Ruffles, P. (2005) Lighting Guide 7 Office lighting. London, SLL.
14. BSI, (1998). BS EN ISO 9241-7:1998 Ergonomic requirements for office work with visual display terminals (VDTs) – Part 7: Requirements for display with reflections. London, BSI.
15. BSI, (2002). BS EN ISO 13406-2:2002 Ergonomic requirements for work with visual displays based on flat panels – Part 2: Ergonomic requirements for flat panel displays. London, BSI.
16. Pawlak, U. and Roll, K.F., (1990). VDTs: Setting levels for reflected luminance. Siemens Review, 57(4): p. 26-29.
17. Howlett, O.A., (2003). Reflectance characteristics of display screen equipment: application to workplace lighting design. Lighting Research and Technology, 35(4): p. 285-296.
18. IESNA, (2004). RP-01-04 American National Standard Practice for Office Lighting. New York, IESNA.
19. Miller, N. J., Boyce, P. & Ngai, P. Y. (2001). A metric for judging acceptability of direct luminaires in computer offices. Journal of the Illuminating Engineering Society, 30:p. 12-29.
20. Becker, M.E. Evaluation and characterization of display reflectance. Display, 19(1): p. 35-54.
21. Lloyd, C.J., Mizukami, M. and Boyce, P.R., (1996). A preliminary model of lighting-display interaction. Journal of the Illuminating Engineering Society, 25: p. 59-69.