The Model of DSE User Acceptability and Performance:
Derivation of new lighting recommendation for the classroom of the future

THARINEE RAMASOOT[1], STEVE FOTIOS[1]

[1]School of Architecture, University of Sheffield, Sheffield, UK

ABSTRACT: An experiment was carried out to investigate the relationship between lighting, display screen luminous properties and users' visual acceptability and visual performance which will be used to develop a model of Display Screen Equipment (DSE) user acceptability and performance. This article discusses the preliminary results from the adjustment method of assessment to define observers' acceptability of screen reflections. Based on three visual criteria, disturbance, contrast and clarity, the results suggest that the limits of luminaire luminance prescribed in current guidance, BS EN 12464-1:2002 and SLL Lighting Guide 7, are too prescriptive– modern display screens in classrooms can tolerate higher luminances. This includes interactive whiteboards of which the threshold luminances have not been previously reported. The results are being further analysed to determine effects of glare source size and viewing angle, and the results are being validated using a second method of assessment, category rating.
Keywords: classroom, lighting, display screen, interactive whiteboard, reflection

INTRODUCTION
Lighting for the Classroom of the Future is an EPSRC funded research project at the University of Sheffield. This project is developing a new strategy for lighting recommendations for multi-media school classrooms where the use of display screen equipment will be vastly increased. This paper discusses the preliminary results from an experiment carried out to investigate the relationship between lighting, display screen luminous properties and users' visual acceptability and visual performance. These data will be used to develop a model of DSE user acceptability and performance.

LIGHTING GUIDANCE FOR THE CLASSROOM OF THE FUTURE
The Classroom of the Future programme was launched by the Department for Education and Skills in the UK in 2003 to experiment with new ideas for designing educational environment for the 21st Century. The programme emphasizes the integration of Information and Communication Technology (ICT) across the curriculum which necessitates increased use of Display Screen Equipment (DSE), the visual interface for ICT. These self-illuminated objects demand different lighting considerations to traditional paper-based tasks. While more illumination leads to increased visual performance for paper-based tasks, this will cause problems with reflections which impair visual performance for the self-illuminated DSE. Furthermore, the learner-centred mode of study means that students in a classroom will be simultaneously working on a wide variety of tasks, some being paper based, some DSE based and papers. Initial work has explored the nature of visual tasks in the Classroom of the Future and conflicts in lighting requirements which demand considerations beyond current lighting guidance for classrooms and DSE environments in details. [1] These earlier stages of the study included using questionnaires to survey classroom users, a field survey of the luminous environment in classrooms, and an in-depth review of current guidance and screen reflection measurements. [2] This work revealed three critical problems:

1. The learner-centred mode of study, in which students work on a variety of self-paced tasks, means that simple solution such as dimming the lighting across a classroom are no longer appropriate.

2. The interactive whiteboard is the most common cause of visual problems with reflections, yet is not addressed in current guidance. One issue is that the whiteboard is observed from a greater range of viewing angles than are personal computers.

3. There are some evidence to suggest that current guidance for DSE environments, BS EN 12464-1:2002 [3], SLL Lighting Guide 7 [4], are out of date:

- The current limits on luminaire luminance are unnecessarily restrictive (e.g. 1500 cd/m² for type I positive polarity display); following improvements in DSE technology, higher luminances are possible without causing disturbance [5].

- Changes in screen technology, such as the use of antiglare coating, have introduced new problems such as haze reflection which are not adequately addressed in guidance. Glossy screens are popular for their high contrast but can suffer from disturbing reflections despite meeting the criteria of BS EN ISO 13406-2:2001. [6]

- The guidance does not accommodate rapid changes in DSE technology.

Thus there is reason to suspect that the current system of predicting acceptability of lighting in rooms using DSE, the luminaire luminance limit is incorrect and a new system is needed.

EXPERIMENTAL DESIGN

Experimental work is being carried out to identify the key parameters of display screen that affect users' acceptance and performance in presence of display reflections. This will be used to develop the model of DSE user acceptability and performance based on interaction between luminous parameters of DSE and lighting.

The tests use a range of display screens chosen to represent those expected to be common in classrooms of the future: PC monitors for individual use and interactive whiteboards for whole-class display. (Fig 1) A Cathode Ray Tube (CRT) monitor, a benchmark of previous research and guidance is also included in the tests for comparison. The range of DSE chosen also represents DSE with different proportion of reflection components (diffuse, specular and haze) and luminous properties, thus reflecting light with different characteristics. CRT and glossy LCD monitors are also tested with negative image polarity screens: these are predicted to tolerate the lowest luminance and thus used for comparison. Image polarity is the terms used in BS 13406-2:2002 [6] to describe the screen conditions; negative polarity is the condition in which bright characters are displayed on a darker background (i.e. positive contrast) while positive polarity is the condition in which dark characters are displayed on a brighter background (i.e. negative contrast). The test display screens and their properties are shown in Table 1.

The luminous properties of these screens were measured, including display luminance, luminance ratio and reflection characteristics. These measurements follow the procedures in two British Standards, BS 9241-7: 1998 [7] and BS 13406-2:2002 [6] currently used to classify screen reflection tolerance. An alternative method of reflection measurement as used in previous study [8] is carried out to determine details of reflection characteristics that are not covered by the British Standards.

Table 1: Display screens used in the tests and their properties.

No.	Display technology	Display polarity	Maximum Luminance (cd/m²)	Major reflection Component
PC screens				
1	Cathode Ray Tube	Positive	78	Specular
2	Liquid Crystal Display (glossy screen surface)	Positive	153	Specular
3	Liquid Crystal Display (matt screen surface)	Positive	181	Haze
Interactive whiteboards				
4	Front-projection interactive whiteboard	Positive	1407	Diffuse
5	Plasma screen with interactive overlay	Positive	91	Specular +Haze
PC screens tested with negative polarity				
6	Cathode Ray Tube	Negative	70	Specular
7	Liquid Crystal Display (glossy screen surface)	Negative	181	Specular

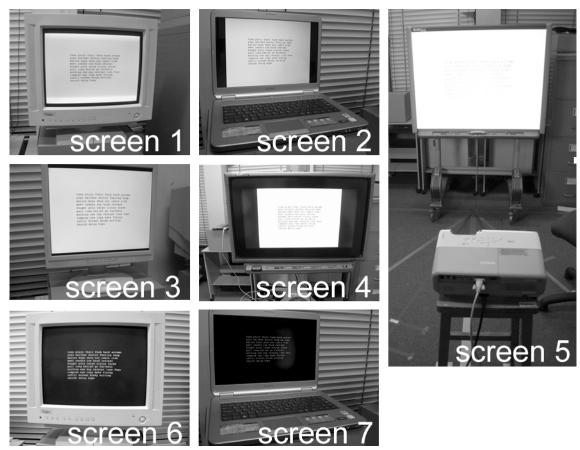

Figure 1: Display screens used in the tests.

We are using subjective and objective assessments to identify the effects of interaction between lighting and display screen on user responses. Subjective assessment of screen reflections is sought using two psychophysical test methods: the adjustment method and the category rating method, similar to previous studies including those upon which current guidance is based. [8-12] The adjustment method requires observers to adjust the luminance of the lighting (source of reflection) to identify the borderline between acceptable and acceptable conditions. [9-10] The rating method requires observers to rate acceptability to rate acceptability of DSE reflections using scales. The results are interpolated using regression to determine the luminance (or luminous conditions) at which reflections are just starting to be unacceptable. [8, 11-12] Both methods identify the conditions at which reflections on display are just starting to be unacceptable for users and hence agreement between both methods will suggest results are more robust. Objective assessment is carried out by measurement of reading speed under the presence of

DSE reflections. This paper discusses the adjustment method and the preliminary results.

The adjustment method use three visual criteria to identify participants' borderlines of acceptability: disturbance, contrast and clarity borderlines. Disturbance borderline or the borderline between disturbing and not disturbing reflections is defined as the discomfort experience that would be just disturbing and could be tolerated for 15 to 30 minutes but would require a change in lighting condition for any longer period. The criterion is similar to previous studies by Hentschel et al. [9] and Pawlak et al. [10], the latter being the reference of current guidance, BS 9241-7: 1998 [7] and BS 13406-2:2002 [6]. Contrast borderline or the borderline between good legibility (high contrast) and poor legibility (insufficient contrast) is defined as the minimum contrast of the text that would allow confident, immediate letter recognition without prolonged scrutiny. The definition is similar to that of 'comfortable readable contrast' defined in a study by Poynter [13] which is the reference of BS 13406-2:2002. Clarity borderline or the borderline between blurred and sharp text is defined as the clarity of the text outline that would allow confident, immediate letter recognition without prolonged scrutiny.

The experimental procedure is set up to evaluate three independent variables and the interactions between them. Two variables are the type of display screen (7 screens with different luminous properties) and size of the source of reflections (visual arcs of 1º, 10º and 15º at the pupil). It was found in pilot studies that there are frequent reflection problems with the interactive whiteboard and this may be because it is viewed from wide range of positions in the classroom. [1] Therefore, the effect of viewing angle is also studied in the experiment with two angles (15º and 30º).

EXPERIMENTAL SETTINGS

The test takes place in a laboratory at the University of Sheffield. The size of the room was 3.40m x 3.90m x 3.20m high. Dark fabric covering the windows is used to obscure daylight. The reflectances of wall and windows blinds, ceiling and floor are 0.60-0.80, 0.96 and 0.17. Ambient light is provided by ceiling-mounted luminaires. The display screens and the observer seat are positioned so that no reflection from the ceiling luminaires is visible on any screen during the test. The illuminance at the top of the working plane (movable desk) is 370 lx.

Screen reflections are generated using a purpose-made light box of face dimensions 550mm x 900mm (Figure 2). Inside the box there are 16 21W tubular fluorescent lamps (Osram Lumilux T5, triphosphor 4000K, cool white). Dimming control is achieved using a Thorn Controllite CDMR, digital signal interface dimmer. The original one-turn potentiometer was replaced by a three-turn potentiometer to reduce the possibility of giving a positional cue. The participant is less aware of dimming range and better able to adjust the lighting level closer to their actual judgement. The enclosure was made from MDF (medium-density fibre) board and the interior was painted with matt white emulsion.

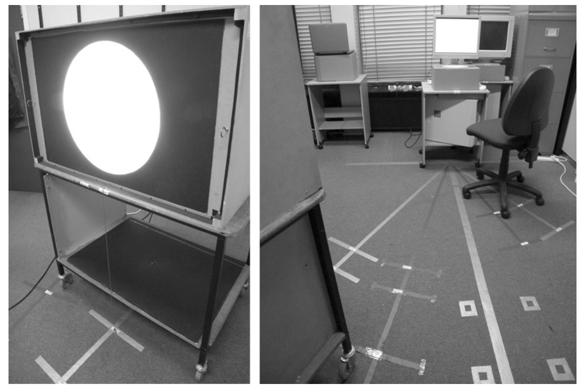

Figure 2: The light box (left) and the arranged positions of participant, display screen and light box in the test (right).

Light is emitted from the light box through an aperture behind which is fitted an acrylic diffusing filter to improve the uniformity of the light. Three sizes of aperture are used in these tests, varied by sliding a black mask across the front face of the box. The experiment uses three sizes of aperture (1º, 10º and 15º) to represent the effect of glare from various bright sources. Our survey of lighting in classrooms suggested that the visual size of luminaires as reflected in display screens is typically less than 5º and that of windows ranges from 5º to 40º. Therefore, the aperture size of 1º subtending to the eye of an observer is used to represent reflections caused by small bright spots such as luminaires when seen reflected on DSE. The aperture size of 10º is chosen to represent the reflections caused by large bright sources such as windows: whilst the British Standards use a 15º glare stimulus, the size of our laboratory did not permit that for all screen types. A pilot study was carried out using four different sizes of screen reflection source (1º, 5º, 10º and 20º); the results demonstrated no significant variation in user response for 10º and above. Kubota [14] suggested that specular reflection coefficient of the display for the light source of 10º can be used to predict the level of reflected glare caused by the windows or other bright surfaces. Therefore, while all screens are tested using the 10º glare source, a 15º stimulus is also tested with the PC screens to confirm the effect of glare source size.

The luminance uniformity of the light source for all aperture sizes conforms to the specifications of BS 9241-7 and 13406-2 (±5% over the central 80% diameter) for the source of luminance to be used in the measurement of reflections from DSE. The average maximum luminance of the light box with 1º aperture is approximately 14,000 cd/m² and the average luminance of the light box with 10º and 15º aperture is approximately 24,000cd/m². During the test, the luminance of the glare source is determined by a reading from an illuminance meter with a receptor fixed inside the light box. The reading from the illuminance meter is converted to the luminance of the glare source by means of a calibration as was done in previous work. [12]

In the test, a participant will sit facing one display screen at a designated angle (15° or 30° from normal to the screen); the light box is positioned at the same angle on the opposite side, but located further away from the screen to avoid direct glare. All screens are placed on their movable stands or on movable desks. The light box is placed on a trolley. This allows the screen on test and the glare source to be moved to the designated position. The centre of the screen, the centre of the aperture of the light box and the eye level of the observer is at a similar height (1.10 m) from the floor. This is achieved by having the observer adjust the height of the chair. The distance between DSE and the observer are varied. These distances are calculated so that similar text on all screens is presented to the observer at the similar angular size. The distance between the light box and the DSE is calculated so that the reflections caused by the light box appears in the designated size to the observer's viewing position and in the middle of the DSE. The floor of the experiment room is masked with these positions for quick and precise movement (Figure 2).

During the test, the DSE are set to their maximum brightness and contrast. A paragraph of 50 random words in 12-pt font size is shown on the screen. The resolutions of the screens used in this work are different; that can affect the legibility of characters which in turn can affect subject's judgements of clarity and contrast. Therefore texts presented on the DSE are created as pictures so that character outlines do not map to display resolutions and characters look as similar as possible for all resolutions.

EXPERIMENTAL PROCEDURE

Twenty-nine test participants were recruited. The age of these ranged from 18 to 68 years old. There were 14 males and 15 females. Those participants who normally wore prescription glasses or contact lens were asked to wear them during the experiment. Before the test, the visual acuity and contrast sensitivity of participants was assessed using standard Landolt ring tasks.

The experiment was carried out with one participant at a time. Each participant saw all combinations of DSE type, size of glare source and viewing angle. The orders of these were randomised to avoid bias. The adjustment procedure was adapted from the method used in a previous study. [10] The starting luminance level of the glare source was at either the highest or lowest luminance level permitted by the dimming mechanism. The participant was asked to read the text on the screen and then use his/her judgement to increase or reduce the level of the glare source until the borderline level was found. The experimenter noted the illuminance of the glare source at this threshold which was later converted to luminance. Where the participant's borderline is higher than the maximum luminance setting of the glare source, the maximum value of glare source that aperture size (14,000 or 24,000) plus 1000 cd/m² is used instead. For each test condition, participants were required to complete three adjustments corresponding to three visual criteria: disturbance, contrast and clarity borderlines. For the combination with 1° source, the participants were asked to complete only one adjustment, to identify only disturbance borderline.

DISTURBANCE THRESHOLD LUMINANCE

The objective of this work is to compare the threshold luminances for disturbing reflections in display screens with the limits prescribed in current lighting guidance. In trials using naïve observers, this threshold is difficult to identify. Although an observer can easily tell when a reflection is, or is not, disturbing, there lies between these conditions an extended range wherein such a decision cannot easily be made. It was considered that the mean average would not provide a good estimate of the disturbance threshold due to subjective variance and extreme values in the response set. Following previous work [10] the data are instead analysed to determine the luminances at which 50% and 95% of observers would consider the screen reflection to be acceptable. (Table 2)

Table 2: Disturbance threshold luminance of 7 display screen identified by 3 criteria (95% 50% satisfied observers and Mean), compared with limits of luminaire luminance and limits of surface luminance specified in BS EN 12464-1:2002 and SLL Lighting Guide 7. (cd/m²)

Size	Disturbance threshold criteria	Positive polarity					Negative	
		CRT	LCD glossy	LCD matt	IWB proj.	IWB overlay	CRT	LCD glossy
1°	95% satisfied	2710	618	12966	10369	3614	490	405
	50% satisfied	10015	3366	25000	25000	15874	7898	2167
	Mean	12941	6351	24170	23990	16510	11092	6437
10°	95% satisfied	880	333	2263	602	363	335	306
	50% satisfied	3253	1226	8459	5553	1240	1388	987
	Mean	4192	2316	9232	6546	1900	2512	1828
BS EN 12464-1 and LG7 limits of luminaire luminance								
	Type III screen	500	500	500	500	500	200	200
	Type I,II screen	1500	1500	1500	1500	1500	1000	1000

LG7 limits of surface luminance							
Average luminance	500	500	500	500	500	500	500
Peak Luminance	1500	1500	1500	1500	1500	1500	1500

Consider the 1º source, Figure 2 shows that when the 50% satisfaction threshold is used, all test DSE can tolerate higher far luminance than limits prescribed in LG7.[3] However, when the more conservative 95% satisfaction threshold is used, it is found that the disturbance threshold of the glossy LCD with positive polarity is lower than the recommended limits for Type I and II screens. Disturbing luminance thresholds for interactive whiteboards have not been previously reported. With the front projection interactive whiteboard, the diffuse reflection component dominates. The experimental results suggest that this screen can tolerate reflected glare sources luminance of 10,000 cd/m² or more. The plasma-overlay interactive whiteboard, which has a high specular reflectance component, can tolerate a luminance roughly the same as that of the CRT monitor.

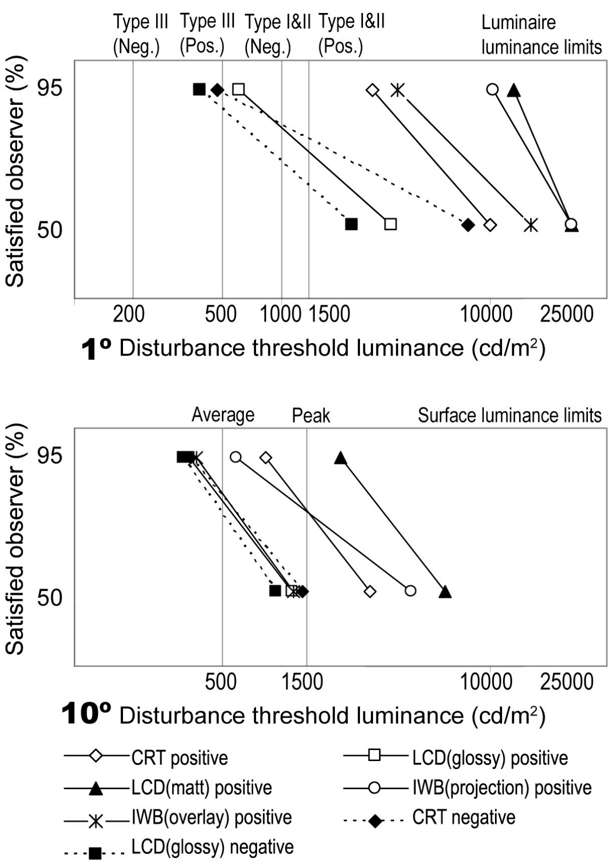

Fig 3: Disturbance threshold luminance of the 7 display screens with 1º and 10º light source, compared with limits of luminaire luminance and limits of surface luminance specified in BS EN 12464-1:2002 and SLL Lighting Guide 7. (cd/m²)

Consider the 10º source, which is intended to represent windows or bright room surfaces. Using disturbance criterion, all of the screens tested tolerate far higher luminance than the recommended limit of average surface luminance (500 cd/m²) when the 50% threshold is used. At the 95% satisfaction threshold only the matt LCD, front-projection interactive whiteboard and CRT have higher disturbance luminance threshold than the standard limit for surface facing the DSE. This suggests the predictable trend that DSE with less specular component can tolerate higher luminance before the reflections become disturbing.

CONTRAST THRESHOLD LUMINANCE

The threshold in this paper means the minimum contrast that allows easy reading, not the threshold for detection. Based on this contrast criterion, when the 50% satisfaction is used, the contrast threshold luminance of all test screens are far higher than the limits prescribed for the average and even the peak luminance of surface facing DSE screen. When 95% satisfaction threshold is used, the contrast threshold luminances are reduced, but are still higher than the standard limit for average surface luminance. (Fig. 4) It should be noted that, unlike other DSE on test, at 95% satisfaction threshold, the contrast threshold luminance of matt LCD screen is considerably lower than its disturbance threshold luminance. This shows that for this screen, with increasing luminance of glare source, character contrast will become a problem for users before they are disturbed by reflections.

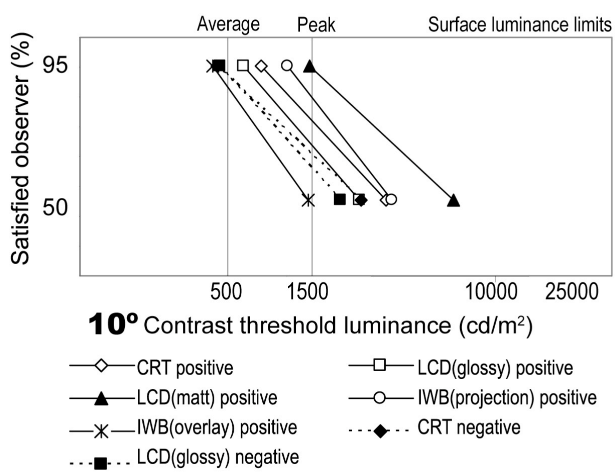

Fig 4: Contrast threshold luminance of the 7 display screens with 10º light source, compared with limits of surface luminance specified in SLL Lighting Guide 7. (cd/m²)

CLARITY THRESHOLD LUMINANCE

It can be seen that clarity threshold luminances of all test DSE are generally higher than contrast and luminance thresholds. Based on clarity criterion, all test screens can tolerate far higher luminance the peak or the average surface luminance facing the DSE when 50% satisfaction threshold is used. When the more conservative threshold of 95% satisfaction threshold is used, all test screens can still tolerate higher luminances than the standard limit for average surface luminance. (Fig. 5)

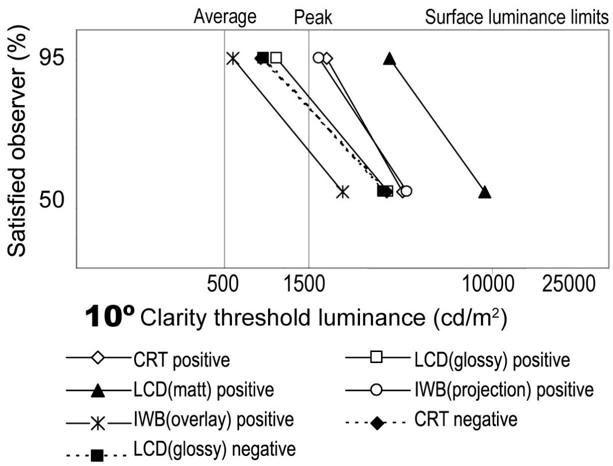

Fig 5: Clarity threshold luminance of the 7 display screens with 10º light source, compared with limits of surface luminance specified in SLL Lighting Guide 7. (cd/m²)

DISSCUSSION

The results have demonstrated that for all three visual criteria used (disturbance, contrast and clarity thresholds), the test display screens which represent those found in ICT classrooms can tolerate higher luminances than the current prescribed limits. This suggests that the limits can be raised or modified, on account of development in display technology. Initial results have also shown the different acceptable luminaire luminances among test DSE with different luminous characteristics and the different threshold luminances when changing the size of glare source. The effects of DSE luminous properties, as well as the effects of luminaire size and viewing angle on the acceptable luminance thresholds are currently being further analysed. Consider the luminances the display screens can tolerate using the three visual criteria, there is a frequent trend of disturbance<contrast<clarity threshold. The relationship between these criteria will be explored further in next stage of the study and compared with the results obtained from the other methodology.

CONCLUSION

An experiment has been carried out to determine threshold luminances at which reflections on display screens become disturbing. The results show that the limits of luminaire luminance prescribed in BS EN 12464-1:2002 and SLL Lighting Guide 7, are too prescriptive – modern display screens can tolerate higher luminances. These results are being further analysed to determine effects of glare source size and viewing angle, and the results are being validated using a second method of assessment, category rating.

ACKNOWLEDGMENTS. This project was carried out with support from EPSRC (grant ref. EP/F029276/1) and scholarship from the Royal Thai Government.

REFERENCES

1. Ramasoot, T. and Fotios, S. (2008b) Lighting for the Classrooms of the Future. Electronic Classrooms: a New Challenge for School Lighting Guidance. BalkanLight 2008. Llubljana, Slovenia.
2. Ramasoot, T. and Fotios, S. (2008a) Acceptability of screen reflections: lighting strategies for improving quality of visual environment in the Classrooms of the Future. PLEA 2008 - 25th Conference on Passive and Low Energy Architecture - Towards Zero Energy Building. Dublin, University College Dublin.
3. Society of Light and Lighting (2005) Lighting guide 7: Office Lighting, Norwick, The Society of Light and Lighting.
4. British Standards Institution (2002b) Light and lighting. Lighting of work places. Part 1: Indoor work places. British Standard. BS EN 12464-1:2002. London, BSI.
5. Howlett, O. (2003) Reflectance characteristics of display screen equipment: application to workplace lighting design. Lighting Res. Technol., 35, 285-296.
6. British Standards Institution (2002a) Ergonomic requirements for office work with visual displays based on flat panels -- Part 2: Ergonomic requirements for flat panel displays British Standard. BS EN ISO 13406-2:2002. London, BSI.
7. British Standards Institution (1998) Ergonomic requirements for office work with visual display terminal (VDTs)-- Part 7: Requirements for display with reflections. British Standard. BS EN ISO 9241-7:1998. London, BSI.
8. Hentschel, H. J., Klein, E., Leibig, J. and Roll, K. F. (1987) Energy-effective direct/indirect office and VDU-lighting systems: Test and application. Journal of the Illuminating Engineering Society, 89-105.
9. Pawlak, U. and Roll, K.-F. (1990) VDTs: Setting Levels for Reflected Luminance. Siements Review, 27-29.
10. Lloyd, C. J., Mizukami, M. and Boyce, P. R. (1996) A preliminary model of lighting-display interaction. Journal of the Illuminating Engineering Society, 59-69.
11. Miller, N. J., Boyce, P. and Ngai, P. Y. (2001) A metric for judging acceptability of direct luminaires in computer offices. Journal of the Illuminating Engineering Society.
12. Wang, X. (1996) An Assessment of Reflected Images in a VDT Screen. Troy, NY, Rensselaer Polytechnic Institute.
13. Poynter, D. (1992) Contrast sensitivity and image recognition: applications to the design of visual displays Displays, 13, 35-43.
14. Kubota, S. (1997) Effects of the reflection properties of liquid-crystal displays on subjective ratings of disturbing reflected glare. J. Light & Vis. Env., 21, 33-42.