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Lighting for the Classrooms of the Future

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1. Introduction

The visual environment affects a learner's ability to perceive visual stimuli and affects his/her mental attitude, and thus affects performance. [1, 2] In order to optimize learner's performance and wellbeing, classroom lighting therefore needs to cater for activities and tools for learning. Information and Communication Technology (ICT) has now become an indispensable apparatus in classrooms and several initiatives have been launched to deliver hi-tech classrooms. This affects visual tasks in classrooms. A review of strategies for classroom lighting is needed to complement new approach to teaching and learning.

2. Classrooms of the Future, ICT and conflicts in lighting requirements

The Classrooms of the Future is a programme initiated by the Department of Education and Skills (DfES) in the U.K. to experiment with new ideas for designing educational environments for the 21st Century. The Classroom of the future will be a flexible, motivating and pleasant environment for learning, taking advantage of developments in ICT, an evolution toward learner-centred, rather than teacher-centred, modes of learning. [3] ICT, including computing and communication facilities, such as desktop and laptop computers, large interactive screens for whole-class discussion, peripherals and connection to the internet, will be widely used in the Classrooms of the Future. [4].

Visual tasks on display screens, the interface of ICT, are fundamentally different from visual tasks on paper or traditional whiteboards which cause conflicts in lighting requirements. Firstly, display screens are mainly vertical, whereas paper tasks which dominate traditional classrooms are typically on horizontal plane. Secondly, most display screens are self-luminous and glossy making their legibility sensitive to lighting. Ambient lighting reduces screen contrast; and reflection of a bright source on screen draws attention away from displayed information.[1, 5, 6] Thirdly, unlike traditional classrooms where all visual tasks are not self-luminous, or workplaces where visual tasks are carried out on one type of display screens, visual tasks in ICT-based classrooms can involve multiple types of display screens being used simultaneously. For instance, a teacher may present a lesson to a class using an interactive whiteboard while pupils take notes using their personal computers. Different visual tasks (non self-luminous and self luminous) having their own criteria for amount and spatial distribution of lighting, contribute to lighting conflicts. [7] If the brightness in the visual environment is unbalanced, switching between tasks with dramatic luminance contrast can put stress on eye adaptation leading to eyestrain. [8]

3. Objectives

The lighting for the Classrooms of the Future project at the University of Sheffield is studying whether the current lighting guidance adequate for the Classroom of the Future as visual tasks are changed. Several issues are investigated including designing lighting to accommodate a variety of simultaneous tasks, investigation of screen glare using visual acceptability models and the review of current lighting guidance for availability and

inadequacy. This paper describes initial work of the investigating lighting design requirements by three routes: (1) a survey of lighting in classrooms where ICT is used; (2) analysis of visual tasks in classrooms and the amount of light required to satisfy visual performance; and (3) a review of current guidance, including current guidelines for classrooms with traditional paper-based tasks and other spaces with Display Screen Equipment (DSE). (Figure 1)

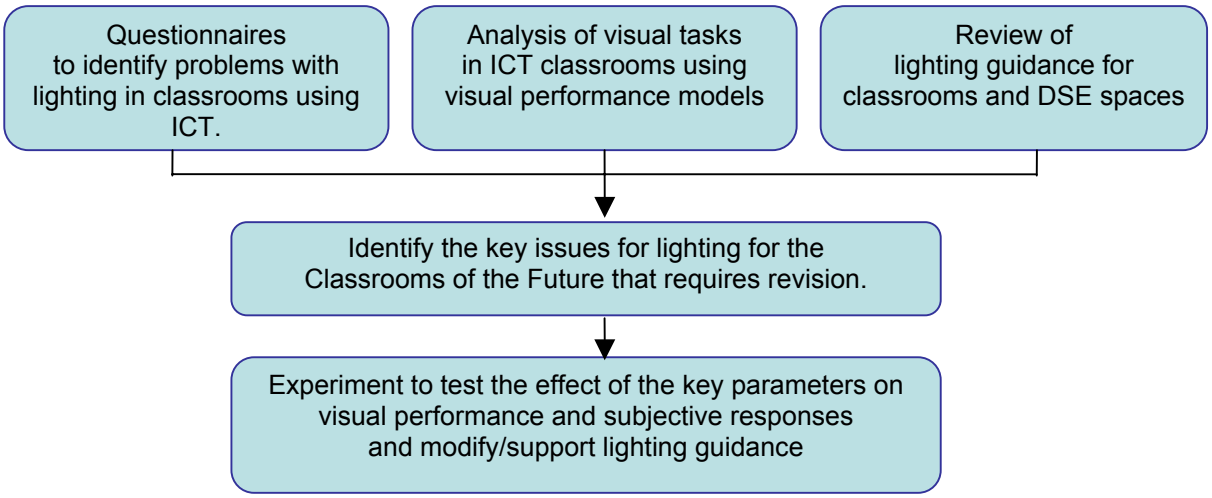

Figure 1: Overview of research structure

4. Classroom survey: identification of critical visual tasks and main lighting problems

The survey among classroom users was initiated to investigate a variety of visual tasks that actually takes place inside the ICT-based classrooms, the current lighting condition of the classrooms and the problems with the classrooms lighting if any exist. The survey was carried out using two questionnaires for two types of classroom users: teachers and students.

4.1 Teacher views

A number of questionnaires were delivered to 10 schools in Sheffield which used ICT extensively in their classes, comprising 4 primary schools and 6 secondary schools. Among this, there were 3 schools participated in the Classroom of the Future initiative.
A copy of questionnaire is shown in the Appendix A. The two-paged questionnaire consisted of 5 parts. Part 1 was about the classroom used as a basis for answering the questionnaire. Part 2 was a survey of ICT and other teaching equipment usage. Part 3 was a survey of classroom lighting. Part 4 was a survey of visual problems in relation to lighting and teaching equipment. Part 5 was about personal details of the respondent which was optional.

Most respondents reported that ICT apparatus had been used in their classrooms for more than 3 years. Average ICT usage (5.64 hours per day) was considerably high in these classrooms confirming that the respondents answered the questionnaire based on ICT-based classrooms. The report frequency of usage of ICT and other teaching equipment is shown in Figure 2. An interactive whiteboard was found in every respondent's classroom making it the most common teaching apparatus. Several apparatus related to computer displays were also common, this being CRT and LCD desktops, laptops, and digital projectors. In general, ICT apparatus were used more frequently than equivalent traditional

apparatus: interactive whiteboards were more common than normal whiteboards and chalkboards; digital projectors were more common than overhead or slide projectors.

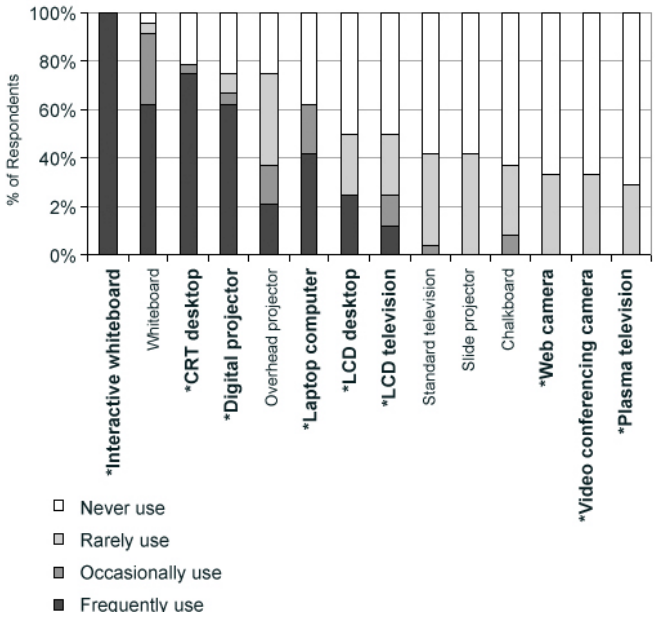

Figure 2: The frequency of usage of ICT and other teaching equipment reported by the respondents

Figure 3 shows summary of positive and negative responses in terms of lighting appraisals and visibility in classrooms. The results are based on responses to yes-no questions. In general, responses suggested that the existing classroom lighting was somewhat acceptable for the respondents though visual problems did exist: 38% could not see information on whole-class displays clearly and 33% have visibility problems using ICT. The lighting problems were illustrated in open-ended questions as a problem with daylight and blackout facilities, a problem with a specific display, namely, an interactive whiteboard, which perform better under low lighting levels.

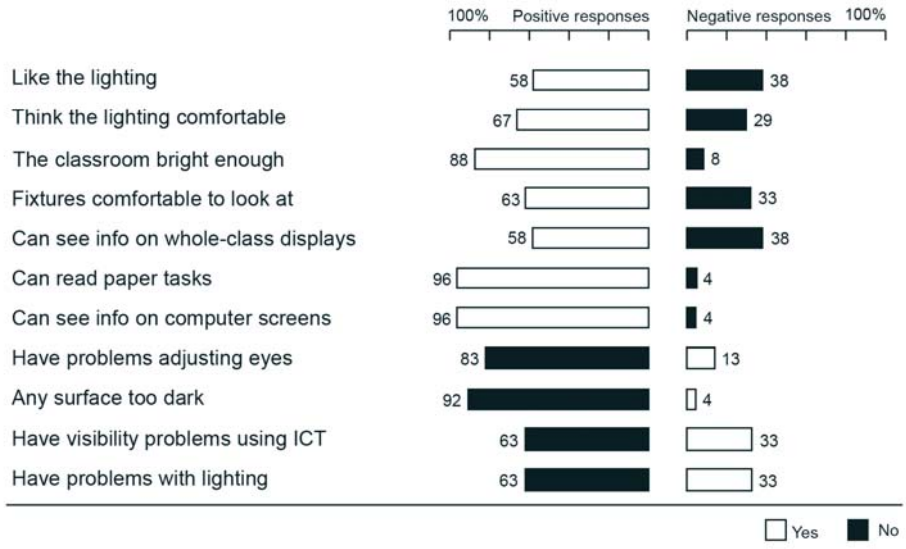

Figure 3: Summary of responses in terms of lighting appraisals and visibility in classrooms

4.2 Student views

A questionnaire for students was targeted at secondary school students because of their that extensive ICT usage. There were 134 responses to the questionnaire in total. The ages of respondents were between 13 to 17 years old (Mean age = 15). A sample questionnaire for students is shown in Appendix B. The questionnaire consisted of 3 parts. Part 1 was personal details of the respondents. Part 2 was questions about the classroom lighting to determine the luminous condition that he/she made the judgement. Part 3 was questions about the respondent's opinions of lighting, ability to see visual tasks, and problem(s) with lighting.

In general, responses suggested that daylight was accessible in these classrooms as 98.5% reported to have windows in their classrooms, however the daylight admittance was limited to some extent as 61.9% reported their blinds were typically down. All respondents (100%) reported to have electric lighting and most of them (97%) said it was typically on. Taking the blinds down and switching the electric light on was possibly attributable to the intention to reduce reflected glare on computer screens.

Figure 4 shows the summary of positive and negative responses of lighting appraisals or visual tasks visibility. Responses suggested that there were legibility problems of several media in classrooms. Considering the fact that all students should be able to receive information clearly as a part of their lesson, one-fourth of the respondents had problems reading information from whole-class displays. Although most of them could read information from computer screens, 41% reported to see superimposed reflections.

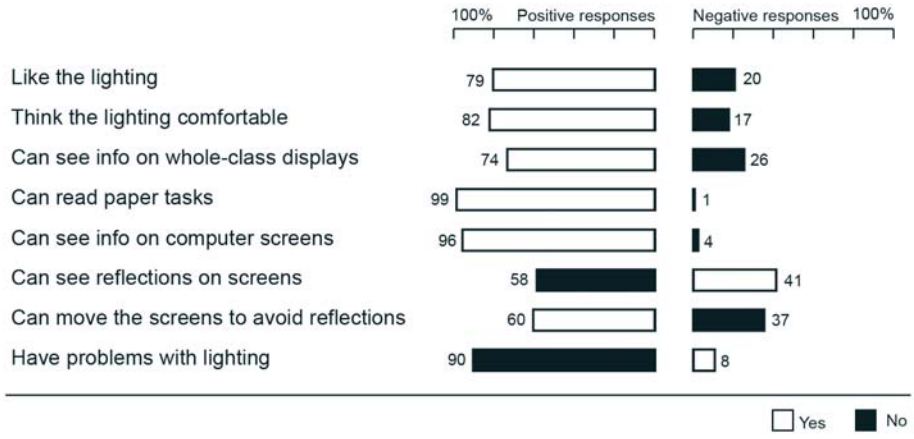

Figure 4: Summary of responses in terms of lighting appraisals and visibility in classrooms

4.3 Critical visual tasks

Based on teachers' responses, a study of association was then carried out to investigate two issues: the critical visual tasks and the main lighting issues for ICT-based classrooms.

A critical visual task was identified as (1) the visual task that takes place frequently in the classrooms and (2) the visual tasks currently have legibility problems and the problems associated with lighting, hence affecting respondents' vision, comfort or opinion of lighting. That is the legibility of the critical visual task should be statistically associated with respondents' opinion of lighting (like the lighting, think it comfortable and have problems with lighting). The 2x2 Chi-square test for independence was used to find the association.

The ability to see information on whole-class displays were significantly associated with whether the teachers liked the lighting (χ^2=9.27, p=0.002) or have any problem with it (Fisher's exact test, p=0.023). For students, the association between the ability to see information and whether students liked the lighting were also significant (χ^2=4.10, p=0.043). A probable association was found between ability to see information on PC and the liking of lighting (Fisher's exact test, p =0.057). It is likely, from the findings, that whole-class displays, especially interactive whiteboards, are critical visual tasks for lighting as they were the most frequently used apparatus; there were comments of legibility problems in relation to both natural and electric lighting; and the visibility of whole-class display statistically accounted for lighting complaints in ICT-based classrooms.

It was found that the ability to adjust computer screens was related to reports of problems at the displays. There is a significant association between the ability to adjust the screen and ability to read information on PC (χ^2= 45, p<0.001) or the experience of reflections (Fisher's exact test, p = 0.007). So although the lighting of classrooms surveyed cause reflections or reduce legibility at computer screens, the students who has ability to adjust their screens might have done that so they experienced no reflections and could read information. Legibility problems at whole-class screens were probably attributed to the fact that unlike computer screens, these big screens could not be easily adjusted for better visibility of the entire audience.

4.4 Lighting issues

Main lighting issues are identified from the issues that respondents reported to have problems and the problems affected respondents comfort or opinion of lighting. That is the report of that problem should be associated with their opinion of lighting. The report of ICT visibility problems was significantly associated with teachers' reports of problems with lighting (χ^2= 8.75, p=0.003) as well as whether they liked the lighting (Fisher's exact test, p= 0.023) or found it comfortable (Fisher's exact test, p= 0.026). In the ICT classrooms surveyed, the legibility at ICT apparatus was responsible for lighting complaints more than other aspects such as room brightness or uniformity.

It is likely that daylight is responsible for ability to read in classrooms. Comments from teachers suggested that daylight interfered with interactive whiteboard. Also, study of association between classroom lighting conditions and students' opinions with lighting in revealed that the position of blinds, which determine the admittance of daylight to the classrooms, were associated with the report of reflections on computer screens.

It seems from the questionnaires that when the ICT equipment is introduced to classrooms, visual problems actually occur. Whole-class displays and personal computer displays are likely to the problematic issues here rather than paper tasks. Responses raised the problems of wash-out images and reflections which up to the 41% of the users experienced. And statistically, visibility problems at ICT equipment associates with the lighting. Daylight is likely to have major effect on the problems.

5. Analysis of visual tasks and visual performance models

The relationship between lighting and visual performance has been investigated in several studies to be used as a system for predicting visual performance using lighting and visual tasks parameters or a system for prescribing illumination based on visual tasks parameter and desired performance. [9-12] In this study, visual tasks are analysed by their levels of

visual stimuli (size and contrast) using models of visual performance in previous studies to determine the visual capacity needed for the tasks and hence the appropriate lighting.

Visual tasks, specifically, reading tasks, in the Classrooms of the Future can be categorized into two groups. The first group, including paper tasks and traditional whiteboards, requires external light source(s) for viewing. The second one involves the visual tasks that have light source(s) included in their systems; hence viewing is possible without ambient lighting. The latter includes tasks on a variety of display screens and projected screens. Although the critical size of both tasks are not much different (subtending between 1x10-5 and 4x 10-4 sr from the observer's eye), analysis revealed the difference pattern of relationship between visual performance and lighting.

For paper tasks (and other non-self-luminous tasks), the relationships between visual stimuli and lighting are straightforward. For a task of a certain size, contrast is constant. When a luminance is increased, visual performance is increased up to a point of diminishing returns. (Figure 5) Using visual performance models, the required adaptation luminance (and the room illumination) in the case of paper tasks can be determined from the given visual task characteristics (size and contrast) and required visual performance.

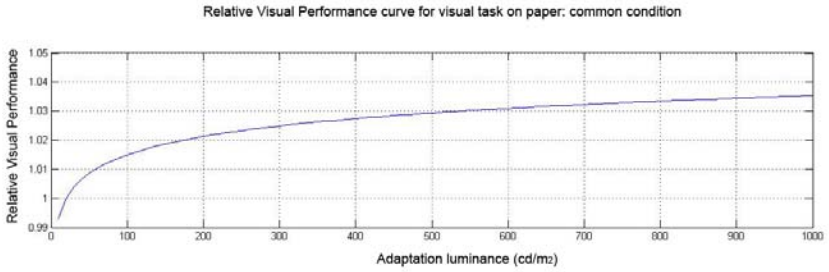

Figure 5: Relative Visual Performance curve for visual task on paper

For self-luminous tasks, the characteristics of visual stimuli are different from paper tasks in 2 aspects: (1) adaptation luminance not only depends on the room lighting but also on the luminance of the screen, (2) luminance contrast is subjected to reduction by the room illumination. The properties of the screen and the lighting are interrelated. If screen luminance is held constant, the room illumination actually reduces screen contrast, hence visual performance. The typical models therefore cannot be used in this case to predict the visual performance at DSE. The properties of the screen, e.g. the display luminance, contrast and reflectance characteristics, will be the additional factors for the prediction. Currently the special model to predict visual performance at DSE is not yet available, however several models were proposed to predict user's acceptance of screen glare based on screen and lighting properties. [13-15]

6. Lighting guidance for ICT-based classrooms

Glare is the discomfort or impairment of vision experienced when parts of the visual field are excessively bright in relation to the general surroundings. Veiling reflection is glare caused by the reflectance of a bright surface reflected on the display screen. This can cause three problems. A reduction in character-to-background contrast reduces the legibility of screen characters, causing impairment of viewing which at the extreme points the contents of the screen become unrecognisable. [16] The reflection can be distracting, taking attention away from the intended task. Finally, the observer eyes may focus toward

the apparently distant reflected image rather than on the screen surface. Glare on display screen equipment (DSE) has long been an important issue in standards for office lighting since 1980s. The issue is, however, relatively new for classroom lighting standards, which usually refers to DSE recommendations written for workplace where computer applications are different.

In the UK, Lighting Guide LG5 [17, 18] offers advice for lighting in classrooms. For control of glare on DSE, LG5 refers to Lighting Guide LG3 [19, 20] which prescribes limit for the luminance of luminaires according to the classification of screens used in the room. DSE screens are allocated into one of three categories according to their reflection tolerance: whether the Image Luminance ratio and the Specular Reflection Luminance ratio of the screen meet the limits specified in BS 9241-7:1998 [21] for CRT screens and BS 13406-2:2002 [22] for LCD screens. These ratios are determined from laboratory measurements of the luminance of characters and their background on the screen under light sources of specified size and luminance. The Image Luminance ratio is based on the legibility of characters on the screen, with different test limits for CRT and LCD screens. The Specular Reflection Luminance ratio is based on user acceptance of veiling reflections on the screen; the same test is used for LCD and CRT screens. For positive polarity screens, the limits of luminaire luminance are up to 1500 cd/m^2 for screen categories I and II and up to 500 cd/m^2 for screen category III.

There is reason to suspect these luminaire luminance limits are incorrect - much higher screen luminances are suggested to be tolerable [23]. Higher luminances may be tolerable due to progressive improvements in screen technology, such as increased brightness, contrast ratio and anti-reflection treatment. 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. Increasing the limit of luminaire luminance would allow more flexibility in lighting design, a greater range of luminaires with less restrictions on spatial distribution.

The UK system controls screen glare by limiting the luminance (cd/m^2) of luminaires, but this says nothing about the size of the glare source. Miller, Boyce & Ngai [15] found that ratings of acceptability of glare on DSE were better predicted by luminous intensity (cd) than by luminance. Luminous intensity is a quantity which describes the power of source to emit light in a given direction. Limiting luminaire luminance may be the wrong approach to controlling screen glare, instead we should be using the luminous intensity of the light source because this accounts also for the size of the glare source

Further sources of lighting design have been reviewed but found to lack adequate guidance for the classroom of the future. Building Bulletin 90 [24] is out of date, for example it discusses lighting for chalk boards but not for white boards, and suggests louver type optical control for light distribution which is now considered unacceptable design because the lack of light on walls and ceiling leads to gloomy interior spaces. The most recent guidance from the Commission Internationale De L'Éclairage (CIE) was published in 1984 [25] since when the characteristics if display screens have changed significantly. There are no active Technical Committees in this area. RP-3-00 (Reaffirmed 2006) Lighting for Educational Facilities [26], US guidance, identifies issues to be considered but does not give sufficient objective design guidance on dealing with potential veiling reflections. A further document [27] offers a range of solutions for classroom lighting, but these are only suitable for typical classrooms, giving set design solutions rather than design criteria, and tends to focus mainly on energy efficiency.

There are several issues pertinent to lighting the classroom of the future that are missing from the previous literature and guidance:

- There are no studies of acceptability of screen glare with interactive whiteboards.
- There is no consideration of lighting design for multiple simultaneous tasks, each having different demands. The traditional response is to use controls, e.g. to dim or raise the illuminance according to the task taking place, but this response is limited in the learner-centred mode of study when many different tasks may be taking place.
- There is a potential conflict between lighting for paper tasks, where higher luminance can lead to better visual performance, up to point of diminishing returns, and lighting for DSE tasks, where a lower luminance may be needed to combat problems of on-screen legibility.

7. Preliminary screen reflectance tests

Preliminary screen reflectance tests were carried out in a laboratory at Zumtobel Lighting Ltd., Middlesex, UK. The tests followed the measurement method in British Standards, BS EN 9241-7 and 13406-2. The standards use two equations, image luminance ratio equation and specular reflection luminance ratio equation, to determine a screen's compliance with the classes of reflection tolerance: Class I, Class II and Class III. A screen is classified into a class when it satisfies both equations under the required conditions of the class, the luminance of the source of reflections, in positive and positive polarities. The research used adapted compliance equations with reference to a previous study [23] to calculated the maximum luminance of the light source (L_{max}) to which the screen can be exposed without causing disturbing reflections.

The results of the preliminary tests with several CRT and LCD displays showed two interesting pieces of evidence:

- The calculated L_{max} of many LCD screens are much higher than the luminaire luminance limits that are prescribed in LG3 (1500 cd/m^2 for screen Class I, the class with the highest reflection tolerance). The finding supports the earlier study that proposed more relaxed luminaire luminance limits. [23]
- A screen can actually pass the compliance test and have high calculated reflection tolerance while reflections are apparent. One of a latest LCD screens in the market with glossy surface was tested. The screen was categorised into class I and, according to the adapted equations, can tolerate higher luminances than what recommended in the standards without causing distracting reflections. Nevertheless observations under normal ambient lighting and in a dark room showed that the reflections on the screen were clearly visible. (Figure 6) This suggests that the current systems for prescribing luminaire luminance limit may not be able to predict the acceptability of users.

Figure 6: Reflections on LCD screen with glossy surface

8. Current status of the work

Initial studies have identified the key issues for Classrooms of the Future as follows:

1. Glare: System for predicting the acceptability of glare for DSE and a range of interactive whiteboard used in classrooms: front-projection, rear-projection and flat-screen overlay
2. Lighting for multiple simultaneous tasks:
    - Display screens for whole-class discussion (i.e. interactive whiteboards) and personal uses (i.e. LCD, CRT monitors)
    - Display screen tasks and paper tasks

The Lighting for the Classrooms of the Future study is currently investigating the acceptability of glare on display screens (i.e. a range of interactive whiteboards, CRT and LCD screens) in classrooms. The experimental works, including the screen measurements and subjective tests, are being set up to determine whether the current guidance for glare can predict the subjective responses to reflections and contrast reduction of display screens in classrooms. Screen measurement will use the test methods prescribed in current guidance (LG3, BS 9241-7, BS 13406-2) to determine the limits of luminaire luminance for the display screens. Subjective testing will two methodologies: an adjustment task and subjective rating tasks, similar to previous works [15, 28], to determine the threshold luminances at which glare just starting to be unacceptable on screens. It is anticipated that the current guidance will not adequately predict the acceptability for these screens.

The next stage of the research will use the experimental data to investigate three tools for integrating DSE with interior lighting. The first tool is the system of screen categories and limits of luminaire luminance – what are appropriate values and the units with which to specify these values? The second tool is a model for predicting ratings of disturbing reflections on DSE from photometric parameters of the screen [13]. Finally, consideration will be given to specification of illuminance in the classroom, and the compromise between paper-based tasks for which higher illuminances may improve task performance and DSE tasks for which higher illuminances may have a deleterious effect on task performance.

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The University Of Sheffield.

Lighting for ICT-based learning environments (The Classrooms of the Future)

This is a survey of the Information and Communication Technology equipment and the lighting used in your classroom. It is a part of my PhD research at the University of Sheffield. If you have any questions or comments please contact myself, Tharinee Ramasoot (arp04tr@sheffield.ac.uk), or my supervisor Dr. Steve Fotios (Steve.Fotios@sheffield.ac.uk).

Please answer the following questions and return this form to the school reception by 20 July 2006.

Information and Communications Technologies (ICT) are the computing and communications facilities and features that variously support teaching, learning and a range of activities in education. ICT includes technologies such as desktop and laptop computers, software, peripherals and connections to the Internet that are intended to fulfil information processing and communications functions.

1. Classroom

1.1 The responses to this questionnaire are given for:

- ☐ My usual classroom, which does not have any special ICT equipment
- ☐ My usual classroom, which has some ICT equipment
- ☐ A special ICT room, which I use occasionally for teaching

If you do not use ICT equipment in your teaching, please ignore this questionnaire.

1.2 For how long has ICT apparatus been used in this room?

☐ 0-1 year ☐ 1-3 years ☐ 3 years or more

1.3 Approximately how many hours per day is ICT used in the classroom? ..... hours.

2. ICT and other teaching equipment usage

What equipment is used in this classroom and how often? (Please tick all that apply)

	Frequently use	Occasionally use	Rarely use
☐ Chalkboard	☐	☐	☐
☐ Whiteboard	☐	☐	☐
☐ Overhead projector	☐	☐	☐
☐ Slide projector	☐	☐	☐
☐ Digital projector	☐	☐	☐
☐ Standard Television (CRT)	☐	☐	☐
☐ LCD display or LCD television	☐	☐	☐
☐ Plasma display or Plasma television	☐	☐	☐
☐ Desktop computer (with CRT monitor)	☐	☐	☐
☐ Desktop computer(with Flat Panel Display)	☐	☐	☐
☐ Laptop computer	☐	☐	☐
☐ Interactive whiteboard	☐	☐	☐
☐ Web camera	☐	☐	☐
☐ Video conferencing camera	☐	☐	☐

3. Classroom lighting

3.1 What lighting is used in this classroom?

☐ Mainly daylighting ☐ Mainly Electric lighting ☐ A combination of daylighting and electric lighting

3.2 Do you have any control on the amount of daylight during lesson? ☐ Yes ☐ No
(e.g. control over blinds)

3.3 Do you have any control on the amount of electric light during lesson? ☐ Yes ☐ No
(e.g. dimming or switching lights on and off)

4. Opinions on lighting (These questions refer to when the electric lighting is on.)

4.1 Do you like the lighting in this classroom? ☐ Yes ☐ No

4.2 Is the lighting in this classroom comfortable? ☐ Yes ☐ No

4.3 Is this classroom bright enough? ☐ Yes ☐ No

4.4 Are the lighting fixtures comfortable to look at? ☐ Yes ☐ No

4.5 Can you see information on the whole-class display equipment clearly? ☐ Yes ☐ No
(i.e. chalkboard, whiteboard, interactive whiteboard, or other large screens)

4.6 Can you see information on the paper task (books or paper) clearly? ☐ Yes ☐ No

4.7 Can you see information on your workstation (desktop or laptop) clearly? ☐ Yes ☐ No

4.8 Do you have problem adjusting your eyes when working with different media in this classroom? ☐ Yes ☐ No

4.9 Are any surfaces in this classroom too dark? ☐ Yes ☐ No
If yes, please specify.
.....

4.10 Do you have visibility problem using ICT equipment? ☐ Yes ☐ No
If yes, please tick all that apply.

☐ Glare ☐ Reflections on screen ☐ Blurred images on screen ☐ Flicker on screen

☐ Other Please specify .....

4.11 Do you have any problem with lighting in this classroom? ☐ Yes ☐ No
If 'yes', please comment

.....

.....

.....

5. Personal details (optional)

5.1 Your name: .....

5.2 Your school: .....

5.3 Your email address: .....

THANK YOU FOR YOUR TIME AND PARTICIPATION

Appendix A: A sample of questionnaire for teacher

Appendix B: A sample of questionnaire for student

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Lighting for the Classrooms of the Future

Part 1 Personal Details (optional)

Your school:.....

Year:.....Age:..... Gender:.....

Do you normally wear glasses or contact lenses? ☐ Yes ☐ No

If yes, are you wearing them now? ☐ Yes ☐ No

Part 2 Classroom Lighting

2.1 Are there windows in this classroom? ☐ Yes ☐ No

2.2 Do the windows have blinds? ☐ Yes ☐ No

2.3 Are the blinds typically up or down? ☐ Up ☐ Down

2.4 Is there electric lighting in this classroom? ☐ Yes ☐ No

2.5 Is it usually on? ☐ Yes ☐ No

Part 3 Opinions on lighting

3.1 Do you like the lighting in this classroom? ☐ Yes ☐ No

3.2 Is the lighting in this classroom comfortable? ☐ Yes ☐ No

3.3 Can you usually see information on the whole-class display equipment clearly? (For example, whiteboard, interactive whiteboard, or other large screens) ☐ Yes ☐ No

3.4 Can you easily read paper tasks on your desk clearly? ☐ Yes ☐ No

3.5 Can you see information on your PC clearly? (For example, desktop or laptop) ☐ Yes ☐ No

3.6 Can you see windows or light fittings reflected in the screen? ☐ Yes ☐ No

3.7 Can you adjust your screen to get rid of these reflections? ☐ Yes ☐ No

3.8 Do you have any problem with lighting in this classroom ☐ Yes ☐ No

If 'yes', please comment

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Date: .....Time: .....

THANK YOU FOR YOUR TIME AND PARTICIPATION

Note for teachers: Please return the completed questionnaire to your school office or send to Tharinee Ramasoot, School of Architecture, University of Sheffield, Sheffield S10 2TN or email: arp04tr@sheffield.ac.uk.