Exploring Simple Assessment Methods for Lighting Quality with Architecture and Design Students

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ABSTRACT: Architecture and design students are frequently required to establish suitable lighting conditions for the buildings and spaces they design as part of their studio courses. While lighting design guidelines are available, students find out quickly that lighting quality is a complex issue that cannot be assessed by simple equations or rules-of-thumb. Balancing the many and often contradictory aspects of energy efficiency and high quality lighting design is a complex undertaking not just for students.

The work described in this paper is one result of an academic staff exchange between the Schools of Architecture in Copenhagen (Denmark) and Victoria University of Wellington (New Zealand). The authors explore two approaches to teaching students simple assessment methods that can contribute to making more informed decisions about the luminous environment and its quality. One approach deals with the assessment of luminance ratios in relation to computer work and presents in that context some results from an experiment undertaken to introduce the concept of luminance ratios and preferred luminance ranges to architecture students. In the other approach a Danish method for assessing the luminance distribution within a visual field is discussed.

Students participating in the experiments began to understand how quantitative measures relate to qualitative experiences, a skill that is likely to be very useful in later architectural or design practice.

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INTRODUCTION
As part of studio courses architecture and design students are frequently required to establish suitable lighting conditions for the buildings and spaces they design. Many assignment statements provided to the students refer to qualitative – rather than quantitative – descriptors and emphasise the connections between architectural form and luminous environments as experienced by potential occupants. This involves both daylight and artificial light. At the same time, students are expected to be aware of the energy implications of any proposed lighting scheme, especially when working on sustainable design assignments.

While lighting design guidelines are available, students find out quickly that lighting quality can at best be described as a complex issue and cannot be assessed by simple equations or rules-of-thumb. Criteria for the assessment of lighting design solutions are thus often limited to establishing and checking illuminance levels.

Experts agree that satisfying illuminance requirements is an important – but small – part of the story. Many other aspects contribute to lighting quality. However, few methods are easy enough to use for assessing those other parts of the story, for example luminance distribution and ratios. This leaves students to struggle with making appropriate decisions. Balancing the many and often contradictory aspects of energy efficiency and high quality lighting design is a complex undertaking not just for students.

Simple assessment methods will of course not provide students with a recipe for lighting quality, but can perhaps lead students one step further than simply providing sufficient lighting in terms of illuminance. Whether this is one step towards lighting quality or just one step away from bad lighting is, of course, debatable.

Most lighting guidelines and standards contain recommendations for luminance distribution and ratios, especially in relation to work environments. Common ratios are 1:3 or 3:1 between a task and its immediate surround and 1:10 or 10:1 between a task and its more distant surround. These ratios appear to be universally accepted, although there are variations. The Danish standard for artificial lighting in working environments [DS 700, 1997] is an example of such a variation, since the standard solely recommends that the luminance of the surround of a given task should be of the same order of magnitude as or darker than the task luminance.

In addition to such variations, the recommended luminance ratios are challenged by the fact that most people will tolerate luminance ratios that clearly exceed the recommended ratios if they are provided with conditions that present...
“daylight with a view” [Osterhaus 2002]. There appears to be little doubt that windows with a view are highly desirable amenities. Many national lighting standards and codes require windows and views to be provided in working environments occupied on a regular basis and for extended periods of time [Osterhaus and Donn 1998]. But how much of a view do people need to trade for a certain reduction in glare perception, for example a one-point reduction on Hopkinson’s daylight glare index scale? How does that affect the acceptable luminance ratios?

The question of luminance ratios, and lighting design in general, might even become more complex in the future, as lighting design might have to support health issues beyond what is considered in current lighting design practice. New research presented at a symposium of the International Commission on Illumination on lighting and health [CIE, 2004], indicates that interdisciplinary studies are leading to a better understanding of the complex relationships between the non-visual effects of lighting and building occupant health. The question remains how these results can be translated into suitable lighting design criteria and tools.

Computer simulations can help establish glare indices and luminance distribution to some extent, but that usually remains fairly abstract in the students' mind. Likewise, the availability of luminance mapping cameras has made it easier to capture images of luminance distribution across the visual field of an occupant, but few architecture or design schools currently have access to such equipment due to its cost. Investigations are under way to assess the application of more simple digital cameras and image processing tools to provide such capabilities at a fraction of the cost [Osterhaus et al, 2005]. Hand-held luminance meters have been available for many years, but require significant familiarity with making luminance assessments to produce reliable data. And even then, there is no clear guidance on where to measure luminance values to arrive at the recommended ratios. It is essentially experience on which a designer relies for much of the time.

All of this leaves students, who by definition do not have the experience of architects, lighting designers or building scientists, in a difficult situation. As educators, we therefore attempt to make qualitative assessment accessible to students through subjective personal experiences and objective physical measurements. Then we attempt to establish correlations between the two that students can understand. The work described in this paper is one result of an academic staff exchange between the Schools of Architecture at the Royal Academy of Fine Arts in Copenhagen (Denmark) and Victoria University of Wellington (New Zealand). The authors explore two approaches to teaching students simple assessment methods that can contribute to making more informed decisions about the luminous environment and its quality.

One approach deals with the assessment of luminous ratios in relation to computer work. An experiment with architecture students at the School of Architecture in Copenhagen was undertaken to introduce the concept of luminance ratios and preferred luminance ranges in one of the students' regular work environment, a computer teaching laboratory.

In the other approach a Danish method for assessing the luminous distribution within a visual field is discussed. The purpose of these two supplementary approaches is to facilitate students' understanding of the correlation between quantitative measures and qualitative experiences. Here, students looked more broadly at their design studio environment and its luminous conditions utilising measurements of luminance at various points in a visual scene in conjunction with a graphic assessment method that has been part of the teaching of light and illumination at the School of Architecture in Copenhagen for a number of years.

**Luminance ratio experiment in a real computer work situation**

Recent research has indicated that the preferred luminance ratio between a computer screen as task luminance and its immediate surround is in the area of 1:1.6, ie that the surround luminance is slightly brighter than that of the computer screen [Osterhaus and Bailey, 1992]. This agrees with the luminance ratios recommended by many international sources [see Osterhaus, 2002], but contradicts the recommendations of luminance ratios in the Danish standard, which suggests that the luminance of the surfaces surrounding a computer screen should be of the same order of magnitude as - or darker than the computer screen.

This may be challenged by resent research results on the biological effects of light, which show that exposure to bright (cool) light during daytime, as well as total darkness during nighttime, is essential for maintaining and resetting the biological clock [CIE, 2004]. It has been suggested that exposure to bright light during daytime can improve the productivity and health status of office workers, and also that there might be a necessary daily light dose that is higher than the light exposure of most individuals in industrialised nations [Veitch et al, 2004]. This light dose needs to be specified in terms of the light at the viewers' eyes, rather than the viewed surfaces for which there are currently illuminance requirements. In general this means that lighting design in the future might extend much further than the current parameters of good lighting and include human health considerations. Experts already suggest that the terminology used to describe lighting quality characteristics needs to be revised.

This seems to indicate that building occupants might need to be provided, at least for short intervals, with luminance levels much greater than currently experienced in interior spaces. How this might be done without creating glare or visual discomfort, not to mention significantly increased energy consumption, is not yet resolved. One possibility for office spaces with computer workstations might be the introduction of luminous surfaces of variable luminance behind the computer screen.

The contradictions between international and Danish recommendations on luminance ratios, the possible challenges for future lighting design, and the intentions to introduce luminance ratios as a simple assessment method to
architecture students, led to an experiment conducted at School of Architecture in Copenhagen as an integral part of teaching students about designing for and assessing lighting quality.

It was an important aim of this experiment to investigate the students’ choice of background luminance (while working on assignments for a computer-aided design course) in a reasonably challenging working and learning environment with a setup that provided background luminances equal to or brighter than the task luminance of the computer screen. Would these ‘real’ working conditions yield similar results as the controlled laboratory experiments from pre-computer days that gave rise to the commonly applied luminance ratios? Would the results of this ‘real’ working conditions yield similar results as the controlled laboratory experiments of visual comfort that indicates a preferred luminance ratio between computer screen and background luminance in the area of 1:1.6 [Osterhaus and Bailey, 1992]? Which background luminance would the students choose when provided a luminous background varying from a luminance in the same order of magnitude as the computer screen to as high as 2,000cd/m²? How consistent would the students’ choice of preferred background luminances be and how much would each individual change the setting during the day and/or from day to day?

**Experimental Set-up**
The experiment was conducted in the CAD teaching laboratory located in a large attic space of one of the former Naval barracks at the Royal Academy of Art’s School of Architecture in Copenhagen.

Three backlit translucent luminous panels mounted against an exterior wall and sloping ceiling were positioned so that they formed a vertical backdrop for two computer display monitors each (Fig. 04). Each backlit panels diffused the light of a bank of 10 dimmable T5 fluorescent lamps (120mm long), producing panel luminances from approximately 40 to 2,000cd/m². This was based on the assumption that the average luminance of the computer screen would be about 40-50cd/m². The monitors were cathode ray terminal (CRT) screens. However, in reality the average computer screen luminance was found to be only around 21 cd/m², ranging from 12 to 66cd/m², due to the applications students used (predominantly 3D Studio MAX/VIZ). Each panel was lit by fluorescent tubes of a different correlated colour temperature, in this case 2,700K, 3,000K and 6,500K. A very small amount of daylight entered the attic space through five small skylights in the roof plane. In addition, fluorescent uplighting with slightly varying, but predominately warm (2,700K) correlated colour temperature. The average horizontal illuminance at workplane height was measured at approximately 100lux without the luminous panels.

![Figure 01: Photographs and drawings of the experimental set-up showing the computer workstations and their respective luminous panels.](image)

**Method**
The luminous panels would be preset at their minimum luminance of approximately 40cd/m² every morning. After one hour, students would be asked whether they were satisfied with the setting of the background luminance or
whether they preferred it to be changed. Whether it was changed or not, each student's choice of background luminance would be registered together with the luminance of the computer screen at that specific time. After another hour, this procedure would be repeated. The rest of the day students were allowed to change the background luminance themselves and would report their general choice the following morning. Also, as students became familiar with the set-up, they were allowed to change and set the background luminance themselves in the morning. In any case, the registration of the results would still happen after 1 and 2 hours. The course started at 9.15 am, recordings were made at approximately 10.15 and 11.15 am. It was also possible to completely switch off the luminous background panel, resulting in an average reflected luminance at the panel of approximately 18cd/m².

Ideally it should have been students enrolled in a lighting course who took and recorded measurements and preferences in order to gain experience and understand the correlation between quantitative measures and qualitative experiences. That was not possible, but those students did get the opportunity to experience the set-up for themselves for brief periods, thus gaining some experience with the measurements and assessments of luminance ratios. Since these experiences were not recorded, they will not be part of the results of this experiment.

Results
Fifteen students participated in the experiment that lasted for four weeks. On average, the students participated in the experiment for three days. There were 83 recorded preference settings. 39 of these settings resulted from six students who were seated at a panel by themselves. The remaining 44 settings were selected by two students in agreement. Out of the 83 recorded settings, the luminous background was turned off in 14 cases (17%). When the luminous background was turned off, the luminance was in the range of 13 to 22cd/m², ie the luminance ratio between computer screen and background luminance was approximately 1:1. In six of the settings (7%), the luminous background remained or was set at its minimum, resulting in background luminances in the range of 40 to 50cd/m² and a luminance ratio between computer screen and background of approximately 1:2. The remaining 63 recorded settings (76%) involved background luminances higher than 50cd/m², resulting in luminance ratios between computer screen and background from 1:2 to 1:25.

The overall average luminance ratio between computer screen and background was 1:6. The overall maximum ratio was 1:25. The lowest recorded ratio was 1.6:1, ie the background luminance was slightly darker than that of the computer screen. With this set-up, it was not possible to select ratios lower than this.

As can be seen from the graph, the preferred background luminance selected varied with correlated colour temperature.

- For 2,700K the average luminance ratio between computer screen and background was approximately 1:12.
- For 3,000K the average luminance ratio between computer screen and background was approximately 1:4.
- For 6,500K the average luminance ratio between computer screen and background was approximately 1:5.

Another observation is related to individual or mutual luminance selections.
- For students who could select the background luminance individually (students 1, 2, 3, 4 and 11), the average luminance ratio between computer screen and background was approximately 1:10.
- For students who had to agree on the background luminance with another student, the average luminance ratio between computer screen and background was approximately 1:3.
With regards to the latter two statements, it is unclear whether these differences were due to the difference in correlated colour temperature of the lamps or the difference of students making individual or mutual choices. Sample sizes were unfortunately much too small for any statistical significance testing.

Figure 03: Recordings of computer screen luminance ($L_s$) and background luminance ($L_b$). All measurements are in cd/m$^2$.

Generally students did not change the background luminance much in the afternoon once their preferred settings were found. However, students appeared to be pleased with the provision of personal control over their luminous environment.

The results suggest that the Danish Standard for artificial lighting in working environments might include luminance ratios with background luminance values higher than the computer display screen luminance as most international standards do.

With reference to the high luminance levels that might be expected due to new research of the non-visual effects of lighting on human health and well-being [CIE, 2004], it can be said that none of the participants in the luminance ratio experiment selected background luminance values anywhere near these high levels. This seems to be the case in particular when the luminous background cannot be controlled individually.

**ASSESSING THE LUMINOUS ENVIRONMENT IN A DESIGN STUDIO**

It can be very difficult to determine the quality of the luminous environment in a real work space. Designers therefore attempt to find assessment tools which simplify such tasks.

The subjective impression of a space usually depends on a variety of factors. Many of them are intrinsically linked with the individual experiences and psychological or physiological characteristics of the observer. Another particularly important factor is the average luminance across the visual field which determines the adaptation level of the observer’s eye.

In order to asses the luminance distribution and visibility of objects within a specific visual field of interest, a chart was developed by Sophus Frandsen at the School of Architecture in Copenhagen during the late 1970s, mainly on the basis of work by Hopkinson and Collins [1970]. The chart (Fig. 04) was initially developed to help students understand the concept of light adaptation and brightness perception, but has since become part of the quantitative recommendations in the Danish Standard on artificial lighting in working environments [see DS 700, 1997]. However it seems like the cart is rarely used by lighting design practitioners.

The chart utilises the relationship between the luminance of various parts of the visual field and establishes ratios and boundaries for object discrimination. Adaptation luminance is plotted logarithmically along the x-axis of the chart and represents values from 0.3 ($10^{-5}$) to 10,000 ($10^4$) cd/m$^2$, ie values from twilight to midday sun reflected off a white sand beach. The ratio of object luminance over adaptation luminance is plotted against the y-axis and represents values from 0.001 ($10^{-3}$) to 1000 ($10^3$), also logarithmically displayed. If adaptation luminance and object luminance are equal – and the ratio therefore one – a data point is plotted somewhere along a horizontal line intersecting the y-axis at its centre, ie at 1 ($10^0$), depending on the actual value of the adaptation luminance.
The grey-scale areas forming the chart backdrop indicate the likely borderlines between generally acceptable luminous conditions with good object discrimination and potentially glaring or too dark situations. At an adaptation luminance of 100 cd/m², an object to adaptation luminance ratio of 10:1 (i.e., an object luminance of 1000 cd/m²) would likely be considered to be at the borderline of becoming a potential glare source. At an adaptation luminance of 10,000 cd/m², an object to adaptation luminance ratio of approximately 3:1 (i.e., an object luminance of approximately 30,000 cd/m²) would create the same sensation.

Figure 04: Chart for the assessment of luminance distribution and object discrimination in a luminous environment.

Method
As part of an educational exercise testing the application of this method in a design studio environment, students were asked to determine various luminance values and ratios in their visual field and assess their likely impression. In doing so, the students had an opportunity to relate their subjective impressions of a space to their own objective measurements.

Figure 05: An example of student work illustrating the application of the chart for graphic assessment of luminance distribution, visibility of objects and subjective impression of luminous environments.
Results
In general, students can easily learn to use the chart in one day (theoretical introduction, presentation of scheme, exercise using the scheme for subjective personal experience and objective physical measurements, presentation and discussion). Through application of the chart in the assessment of luminance distribution and subjective impressions of the luminous conditions in a familiar environment, students are made aware of some fundamental aspects of lighting quality. It is our experience that the exercise helps students understand the relationship between subjective impressions and objective measurements in lighting design applications.

However, students were often unsure where to measure luminance, and successive measurements under the same lighting conditions of supposedly the same object sometimes resulted in dramatically different luminance values due to slight variations in measurement position or direction. This can have a significant effect on the objective assessment of the space. No clear guidance is provided in the literature on where to measure luminance values to arrive at the recommended ratios. Some experts recommend to measure where the contrast is highest, others in the areas that are more representative of the surfaces in question.

In our experience students also tend to forget how to use the chart after a short time of not using it. This appears to be due to complications in plotting measured luminances as ratios in relation to the luminance adaptation level on a logarithmical scale. The chart seems most useful in an educational context where the aim is to create an understanding of how quantitative measures relate to qualitative experiences. The chart is useful in analysing an existing luminous environment, but less useful as a tool in the design stages of a lighting project in its current nomograph-like paper-based form.

CONCLUSIONS
The two experiments presented in this paper provide possible approaches to teaching architecture and design students about the assessment of fundamental lighting quality descriptors. While the exercises are in no way comprehensive, they provide a starting point for students to engage with the learning material. Students generally responded well to the challenge of moving beyond the mere assessment of illuminance levels and perhaps develop their understanding of lighting design a step further.

Figure 06: Examples of the simple assessment of the luminous distribution and visibility of objects in relation to a computer work station. The chart shows for instance that the keyboard appears too dark when the blinds are up in set-up 2. With the blinds down, the adaptation luminance is lower, the luminance ratios less extreme and all objects/surfaces within the visual field are visible.
The methods used are simple enough to be applied in a variety of contexts. The conceptual idea presented in Sophus Fradsen’s chart could be explored for transfer into a digital realm and possible integration into lighting simulation programs. It would also be desirable to create a more permanent learning laboratory setting in which students can explore the concept of luminance ratios in much detail. The backlit translucent panels used in the luminance ratio experiment described in this paper could be assembled to allow for flexible application in various ‘realistic’ lighting situations. Different panel arrangements and luminance levels could be tested by students and researchers for a number of lighting environments, from working environments to living and entertainment applications.

However, the exercises also highlighted problems identified on various occasions. While students quickly engaged with the lighting quality descriptors introduced to them and the methods of how to assess them, questions were raised about protocols and instructions for luminance measurements with hand-held spot meters. The authors have observed similar discussions even among seasoned lighting researchers, perhaps indicating a more general need for effective guidance in the assessment of lighting quality. It appears that the current terminology and supporting concepts used in lighting design need to be more clearly defined and consistently used in publications and interactions between professionals. The authors’ experience is that terms or descriptors are frequently applied incorrectly and without a clear understanding of the underlying concepts. Glossaries of such terms in simple format and with illustrative sketches would go a long way. The International Commission on Illumination (CIE) is currently in the process of creating such a document. Another useful addition to the student and designers’ toolkit would be the provision of agreed-upon measurement protocols for each of the suggested descriptors. Present recommended practices or guide documents generally do not provide such information. Professionals have to rely on the experience of colleagues or the user manuals supplied with specific measurement instruments. A compendium of generic measurement protocols would be able to explain what needs to be measured to assess a particular known descriptor and how to do it. Advances in digital imaging and analysis tools should aid in that respect.

Nevertheless, designers will still need to rely on their professional judgement as to which factors and ranges would be important and appropriate for their specific lighting design problem. Lighting designers will certainly not become obsolete, but hopefully better informed and able to respond to the needs of their clients. The professional recognition of skilled, well-educated and creative lighting designers will likely increase as a result, for only they will be able to solve contemporary lighting design problems and achieve high quality lighting installations. Lighting design will continue to be about solving complex problems creatively. Preparing students for that challenge is an important part of our role as educators. Students participating in the experiments described here certainly began to understand how quantitative measures relate to qualitative experiences, a skill that is likely to be very useful in later architectural or design practice. They also became aware of the variations between national and international lighting standard and guidelines.

REFERENCES


