# Impact of Solar Shading Devices on Daylight Quality

## Measurements in Experimental Office Rooms

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## Keywords

Shading devices, solar screens, venetian blinds, lighting quality, daylighting, visual comfort, glare.



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# Abstract

The impact of ten solar shading screens and one venetian blind on daylight quality was studied through measurements in two south-oriented experimental office rooms. The daylight quality was assessed by considering five performance indicators: the daylight factor, the work plane illuminance, the illuminance uniformity on the work plane, the absolute luminance in the field of view and the luminance ratios between the paper task, the walls and the VDT screen. The measurements were carried out under perfect sunny conditions and overcast conditions. The results show that the shading devices can be divided into three distinct groups. Group 1 consists of all dark-coloured screens; Group 2 includes the closed venetian blind while Group 3 includes the white screens and the horizontal venetian blind. The devices of Group 1 produced unacceptably low work plane illuminance and vertical luminance values which resulted in unsuitable luminance ratios between the task, the walls and VDT screen. However, these devices reduced the luminance of the window (sky) to acceptable levels. The devices of Group 3 did not prevent high window luminance but yielded higher levels of work plane illuminance and inner wall luminance, which makes them suitable for traditional paper tasks. They also generated high wall luminance values which resulted in a number of unacceptable luminance ratios between the task, walls and VDT screen. The closed venetian blind (Group 2) was the only device which scored well on all performance indicators considered. It provided ideal illuminance levels for paper and VDT tasks and resulted in favourable wall luminance values for computer work.

# Contents

# List of symbols

| | |
|---|---|
| $A$ | Area ($m^2$) |
| $D$ | Daylight factor (%) |
| $E$ | Illuminance (lx) |
| $E_{av}$ | Average work plane illuminance (lx) |
| $E_{max}$ | Maximum work plane illuminance (lx) |
| $E_{min}$ | Minimum work plane illuminance (lx) |
| $E_R$ | Illuminance, Reference room (lx) |
| $E_T$ | Illuminance, Test room (lx) |
| $L$ | Luminance ($cd/m^2$) |
| $L_{adjacent\_wall}$ | Luminance of adjacent wall ($cd/m^2$) |
| $L_{paper\_task}$ | Luminance of paper task ($cd/m^2$) |
| $L_{shade}$ | Luminance of the shading device ($cd/m^2$) |
| $L_{VDT}$ | Luminance of the VDT screen ($cd/m^2$) |
| $L_{walls}$ | Luminance (average) of the walls ($cd/m^2$) |
| $L_{window(sky)}$ | Luminance measured through the window in the sky part ($cd/m^2$) |
| $RD$ | Relative difference (%) |
| $T_{shade}$ | Light transmittance of the shading device (%) |
| $T_{vis}$ | Visual (light) transmittance (%) |
| $\phi$ | Luminous flux (lm) |
| $\theta$ | Angle between the normal to the light source and the direction of the beam (°) |
| $\rho$ | Reflectance (%) |
| $\Omega$ | Solid angle (sr) |

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# 1 Introduction

This report presents the results of a study of the impact of shading devices on the daylighting quality in typical south-oriented office rooms. The study was carried out through measurements in the full-scale experimental rooms of the Daylight Laboratory at the Danish Building and Urban Research Institute (DBUR), in Hørsholm, Denmark. The measurements were performed simultaneously in two identical rooms: a Reference room, which was totally empty, and a Test room, which was furnished as a typical office room. The daylight quality was evaluated by looking at five performance indicators under perfectly sunny sky conditions and overcast conditions. Under the sunny conditions, each shading device was monitored three times during the day i.e. once in the morning, once at noon time and once in the afternoon.

## 1.1 Terms and definitions

The technical terms used in this report are defined below. Most of these definitions are directly extracted from CIE (1987).

### *Illuminance*

The illuminance $E$ at a point of an area is the quotient of the luminous flux $d\phi$ received by an area element $dA$ containing that point and the area of that element.

$$E = \frac{d\phi}{dA} \tag{1.1}$$

The SI unit of illuminance is the lux (lx).

### *Lux*

One lux is the illuminance produced on a surface of area one square metre by a luminous flux of one lumen (lm) uniformly distributed over that surface.

$$\mathrm{lx = lm \cdot m^{-2}} \tag{1.2}$$

### Lumen

The lumen (lm) is the SI unit of luminous flux. One lumen is the luminous flux emitted in unit solid angle (sr) by a uniform point source having a luminous intensity of one candela.

### Candela

The candela (cd) is the SI unit of luminous intensity. The candela is the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency $540 \times 10^{12}$ hertz and that has a radiant intensity in that direction of 1/683 watt per steradian.

$$\mathrm{cd = lm \cdot sr^{-1}} \tag{1.3}$$

### Luminance

The luminance (in a given direction, at a given point of a real or imaginary surface) is the quantity defined by the formula:

$$L = \frac{d\phi}{dA \cdot \cos\theta \cdot d\Omega} \tag{1.4}$$

where $d\phi$ is the luminous flux transmitted by an elementary beam passing through the given point and propagating in the solid angle $d\Omega$ containing the given direction; $dA$ is the area of a section of that beam containing the given point; $\theta$ is the angle between the normal to that section and the direction of the beam. The SI unit of luminance is the candela per square metre ($\mathrm{cd \cdot m^{-2}}$).

$$\mathrm{cd \cdot m^{-2} = lm \cdot m^{-2} \cdot sr^{-1}} \tag{1.5}$$

### Daylight factor

The daylight factor ($D$) is the ratio of the illuminance at a point on a given plane due to the light received directly or indirectly from a sky of assumed or known luminance distribution, to the illuminance on a horizontal plane due to an unobstructed hemisphere of this sky. The contribution of direct sunlight to both illuminances is excluded. Glazing, dirt effects, etc. are included. When calculating the lighting of interiors, the contribution of direct sunlight must be considered separately.

### Discomfort glare

Discomfort glare is a type of glare that causes discomfort without necessarily impairing the vision of objects. Discomfort glare is a sensation of annoyance or pain caused by high or non-uniform distributions of brightness in the field of view (IES, 1993).

### Disability glare

Disability glare is the type of glare that impairs vision or causes a direct reduction in the ability to see objects without necessarily causing discomfort. Disability glare is due to a scattering of light in the ocular media of the eye, which is not perfectly transparent. This scattered light is superimposed upon the retinal image, which reduces the contrast of the image and may thus reduce visibility and performance (IES, 1993).

## 1.2 Performance indicators

In this study, the daylight quality is assessed by considering five performance indicators:

1. the daylight factor
2. the absolute work plane illuminance
3. the illuminance uniformity on the work plane
4. the absolute luminance values on the vertical plane
5. the luminance ratios between the paper task, the walls and the video display terminal (VDT) screen.

These performance indicators were determined after a review of the literature in the field as well as codes and guides concerning lighting of work spaces (AFNOR, 1990; ISO, 2000; IES, 1993; CIE, 1986; CIBSE, 1994; NUTEK, 1994). This literature review and the rationale motivating the choice of performance indicators is covered in Dubois (2001).

## 1.3 Interpretation of data

The assessment of daylight quality is based on an interpretation of the measured data as presented in Table 1.1.

Table 1.1 Performance indicators and their interpretation.

| # | Performance indicator | Interpretation |
|---|---|---|
| 1 | **DAYLIGHT FACTOR** | |
| | < 1 % | unacceptable |
| | 1-2 % | acceptable |
| | 2-5 % | preferable |
| | > 5 % | ideal for paper work / too bright for computer work |
| 2 | **WORK PLANE ILLUMINANCE** | |
| | < 100 lx | too dark for paper and computer work |
| | 100-300 lx | too dark for paper work / acceptable for computer work |
| | 300-500 lx | acceptable for paper work / ideal for computer work |
| | > 500 lx | ideal for paper work / too bright for computer work |
| 3 | **ILLUMINANCE UNIFORMITY ON THE WORK PLANE** | |
| | $E_{min}/E_{max} > 0.5$ | acceptable |
| | $E_{min}/E_{max} > 0.7$ | ideal |
| | $E_{min}/E_{av} > 0.8$ | ideal |
| 4 | **ABSOLUTE LUMINANCE** | |
| | > 2000 $cd/m^2$ | too bright, anywhere in the room |
| | > 1000 $cd/m^2$ | too bright, in the normal visual field* |
| | < 500 $cd/m^2$ | preferable |
| | < 30 $cd/m^2$ | unacceptably dark |
| 5 | **LUMINANCE RATIOS** | |
| | $0.33 < L_{paper\_task}/L_{VDT} < 3$ | acceptable |
| | $0.33 < L_{paper\_task}/L_{adjacent\_wall} < 3$ | acceptable |
| | $0.33 < L_{VDT}/L_{adjacent\_wall} < 3$ | acceptable |
| | ($L_{paper\_task}/L_{VDT} < 0.33$ or $> 3$ | unacceptable) |
| | ($L_{paper\_task}/L_{adjacent\_wall} < 0.33$ or $> 3$ | unacceptable) |
| | ($L_{VDT}/L_{adjacent\_wall} < 0.33$ or $> 3$ | unacceptable) |

*The normal visual field is the area that extends 90° each side horizontally, 50° upwards and 70° down from the horizon (NUTEK, 1994).

# 2 Method

## 2.1 Experimental rooms

This study was entirely carried out through measurements at the Daylight Laboratory of the DBUR, located in Hørsholm, Denmark. This laboratory has two south-oriented[1] experimental rooms, which are raised 7 m above the ground in order to prevent shading from adjacent buildings or trees (Fig. 2.1).

The two experimental rooms are identical, each measuring 3.5 m (width) by 6.0 m (depth) with a floor to ceiling height of 3.0 m. Both experimental rooms were used in this study. The first room – called the Reference room – was totally empty while the second room – called the Test room – was furnished as a typical office room (Fig. 2.2 and 2.3). All measurements were carried out in both rooms simultaneously in order to study the difference between an empty and a furnished room.

*Figure 2.1* *Picture of the Daylight Laboratory of the DBUR Institute showing the two experimental rooms, which are elevated from the ground (photo Jan Carl Westphall).*

1. The windows of the laboratory can be changed so that north and east orientations can also be studied. However, this study only covers the south orientation.

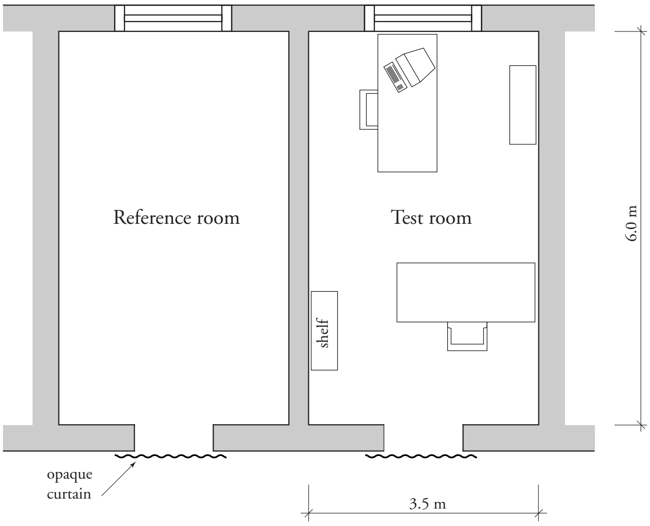



Figure 2.2 *Plan of the experimental rooms in the Daylight Laboratory of DBUR Institute showing the Reference room and the Test room, which was furnished as a typical office room.*

Figure 2.3 *Picture showing the Test room furnished as a typical office room (photo Jan Carl Westphall).*

### 2.1.1 Windows

Each experimental room of the laboratory has a 1.78 m wide by 1.42 m high window. This window is located 0.78 m from the floor and is centred with respect to lateral walls (see Fig. 2.2). The access to each room is through a door located in the wall opposite to the window. This door was removed for the measurements and replaced by an opaque curtain the same colour as the door to allow fixing of the measuring instruments.

The windows of the experimental rooms are double-pane, low-emissivity coated windows with argon fillings from Pilkington (Optitherm S). These windows have the following optical and thermal properties:

- Direct visual transmittance: 72 %
- Diffuse visual transmittance: 65 %
- U-value: 1.1 $W/m^2 °C$

### 2.1.2 Walls, floor, ceiling

The walls of the experimental rooms are covered with a white wallpaper, which is an almost perfectly diffusing surface. The ceiling of the laboratory is made of white suspended ceiling tiles and the floor is covered with a medium grey carpet. The reflectance of each material was measured using a spot luminance meter and a reference reflector. The reflectance obtained for each component is:

- Walls: 81 %
- Ceiling: 88 %
- Floor: 11 %

Note that the ceiling contains embedded lighting fixtures which contribute to a reduction of the overall reflectance of the ceiling. These artificial lights were turned off throughout the duration of the measurements since the study essentially focused on daylighting.

## 2.2 Shading systems studied

A total of ten solar screens and one venetian blind were evaluated and compared with the bare window case. All the shading systems studied were mounted on the interior side of the window. Each system was duplicated to allow for simultaneous measurements in both experimental rooms.

The solar screens were a type of flat roller blind fixed on the interior side and above the window (Fig. 2.4). All the solar screens studied were 1.97 m wide by 1.80 m high and were fixed in a similar way above the window. The screens were wider and longer than the window in order to prevent light leakage on the side of the window.

*Figure 2.4* *Picture of an interior solar screen similar to the ones evaluated in this study (photo Jan Carl Westphall).*

The venetian blind was a standard type with 25 mm wide curved, white aluminium slats. The slats of the venetian blind were either horizontal or closed (see Fig. 2.5). The horizontal slat position is called "VBH" for "venetian blind, horizontal" while the closed slat position is called "VBC" for "venetian blind, closed" throughout this report.

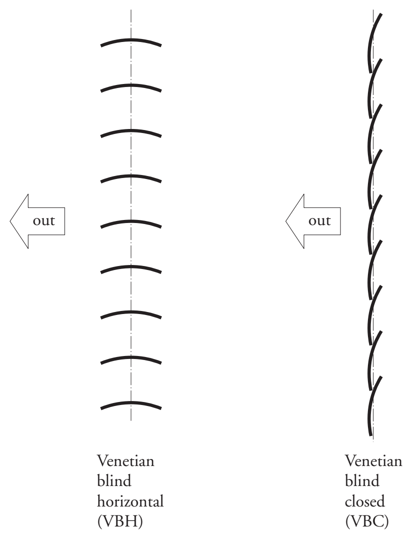



*Figure 2.5* *Drawing showing the venetian blind with horizontal slats (VBH) and closed slats (VBC).*

The screens were given a name at the beginning of the study in order to facilitate identification and communication. This name is used throughout this report. Table 2.1 shows a list of the shading devices tested with their names, colour and a description of the weave pattern as well as the estimated light transmittance. The light transmittance of the shading device ($T_{shade}$) was roughly estimated by measuring the luminance through the screen plus window combination ($L_{shade}$) and the luminance through the bare window ($L_{window(sky)}$) in the sky part and determining the ratio of the two values as follows:

$$T_{shade} = L_{shade}/L_{window(sky)} \tag{2.1}$$

The transmittance was estimated under sunny sky conditions three times a day (morning, noon and afternoon). The values obtained were fairly constant for most systems despite the varying solar angle. The venetian blind and one screen – Black2 – had a variable light transmittance. Black2 had a transmittance of 11 % in the morning, 16 % at noon and 13 % in the afternoon. This means that these shading systems have a significant solar angle dependence.

Table 2.1 List of the shading devices tested with their name and a brief description.

| Name | Type | Colour | $T_{vis}$ (%) | Description |
|---|---|---|---|---|
| **Beige** | Roller screen | Medium brown | 4 | Very regular "diagonal" weave pattern, big thread |
| **Black1** | Roller screen | Black | 9 | Slightly irregular "diagonal" weave pattern with very fine thread |
| **Black2** | Roller screen | Black | 13 | Slightly irregular "diagonal" weave pattern with very fine thread |
| **Black3** | Roller screen | Black | 6 | Slightly irregular "diagonal" weave pattern with very fine thread |
| **Brown1** | Roller screen | Dark brown | 7 | Slightly irregular "parallel" weave pattern with very fine thread |
| **Brown2** | Roller screen | Dark brown | 6 | Very regular "parallel" weave pattern with medium thread |
| **Charcoal** | Roller screen | Dark brown | 7 | Very regular "parallel" weave pattern, very big thread |
| **Plastic** | Roller screen | Medium brown | 3 | Irregular "parallel" weave pattern covered with plastic material |
| **VBC** | Venetian blind | White | 5 | Standard 25 mm curved, white aluminium slats, closed |
| **VBH** | Venetian blind | White | 91 | Standard 25 mm curved, white aluminium slats, horizontal |
| **White1** | Roller screen | White | 27 | Very regular "parallel" weave pattern with very fine thread |
| **White2** | Roller screen | White | 59 | Slightly irregular "diagonal" weave pattern with very fine thread |

The solar screens had different weave patterns as shown in Table 2.1. About half of the screens had "parallel" weave patterns i.e. weave patterns where the threads are horizontal and vertical. The rest of the screens had "diagonal" weave patterns where the threads change direction. It appeared during the measurements that the "diagonal" weave patterns diffused light more effectively than the parallel weave patterns. This was especially apparent by looking at the white screens. Under diffuse lighting conditions, it was difficult to distinguish between the two screens because they looked almost identical. However, under direct sunlight, White2 appeared much brighter than White1, which was verified by the results of the measurements.

## 2.3 Measuring equipment

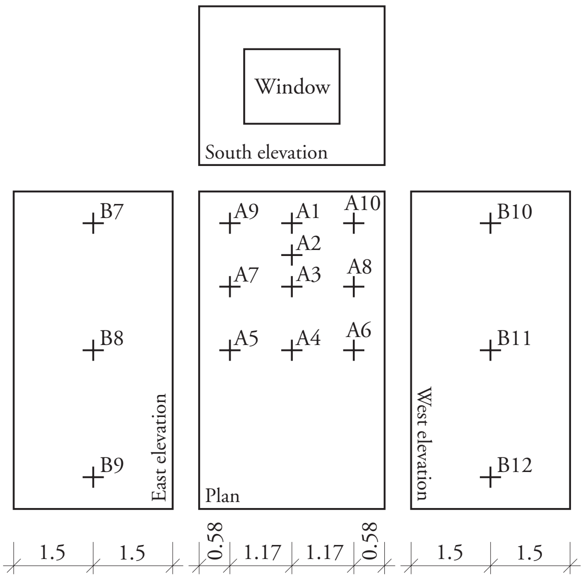
### 2.3.1 Measurement of illuminance

The illuminance on the work plane was measured at 0.85 m from the floor using Hagner lux meters Model SD1 fixed on metal supports arranged as shown in Fig. 2.6. Note that we concentrated the lux meters in the area adjacent to the window (Reference room) since it has been shown (Christoffersen et al., 1999) that 70 % of office workers using a VDT prefer to sit in the third part of the room closest to the window. These lux meters have a spectral sensitivity following the visibility curve of a CIE standard observer and have a cosine correction to compensate for errors due to steep angles of incidence. The zero value of these lux meters was determined by carrying out a series of dark measurements and removing the value measured under total darkness from the final data set.

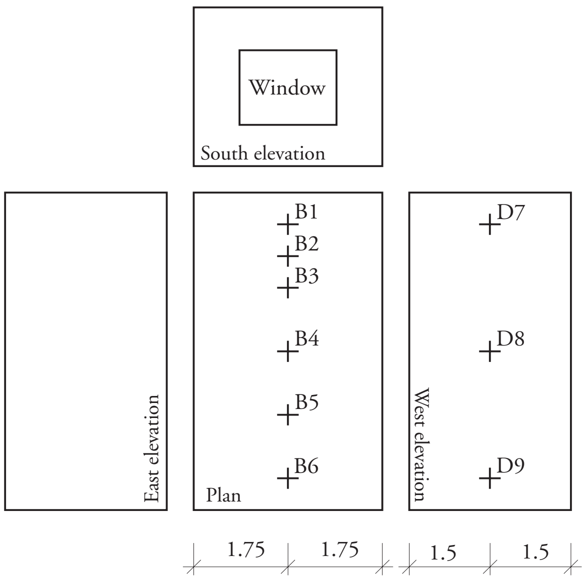
The lux meters were connected to a Hagner multi-channel amplifier Model MCA-1600, which was connected to a datalogger. The datalogger makes the analog to digital signal conversion and saves data before it is retrieved by a nearby computer. The illuminance values were continuously recorded every 30 seconds throughout each day of measurement.

Vertical lux meters similar to the horizontal lux meters were also fixed on the lateral walls of the rooms in order to measure the light incident on these walls. These values were used to verify that the luminance values measured with the CCD camera were correct. The positions of these vertical lux meters are shown in Fig. 2.6.

The exterior global illuminance and the vertical illuminance on the (south) facade from the sky and ground were also simultaneously recorded with lux meters on the roof and facade (Fig. 2.7 and 2.8).




a)




b)

*Figure 2.6* *Position of the horizontal and vertical lux meters in a) the Reference room and b) the Test room.*


*Figure 2.7* *Picture showing the lux meter on the roof for recording the global illuminance (photo Jan Carl Westphall).*

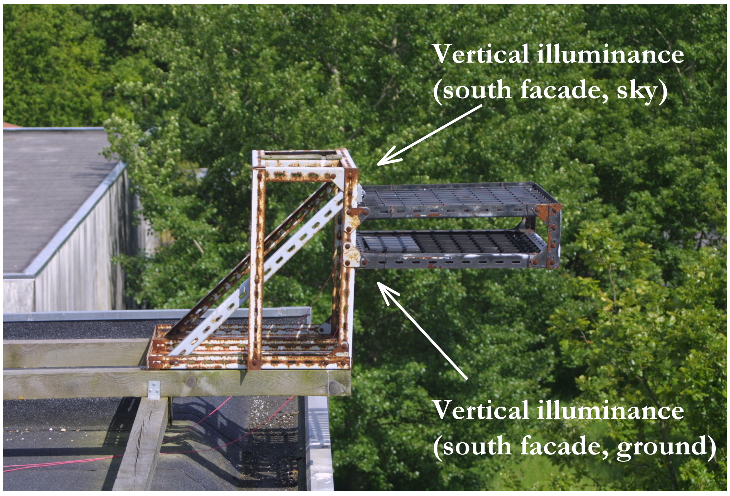



*Figure 2.8* *Picture showing the lux meters on the south facade for recording the vertical illuminance from the sky and ground. The two meters are separated by a black shade (photo Jan Carl Westphall).*

## 2.3.2 Measurement of luminance

The luminance of the walls and window was measured using a calibrated, scientific grade CCD camera IQcam Model III (IQC-3-10-ZM). This camera was calibrated by the company *Instrument Systems Canada* and provided with a filter to adjust the detector's sensitivity to that of a standard CIE observer. The camera comes with a software which allows control of the camera and analysis of the data. This camera allows simultaneous measurement of the luminance in a whole scene. The resulting digital image contains 1300 (horizontal) by 1030 (vertical) pixels corresponding to as many luminance values.

Despite the enormous advantage provided by simultaneous luminance measurements, this CCD camera has two major limitations: its dynamic range is limited to around 5-3100 cd/m$^2$ and its viewing angle is only 32.6° (horizontal) and 25.8° (vertical). In order to compensate for the limitation concerning the dynamic range, the luminance of the sky (through the window) and of sunlight patches in the room was measured with a manual luminance meter Hagner (Universal Photometer) Model S2. The second limitation concerning the viewing angle was compensated for by taking three pictures in each room as shown in Fig. 2.9.

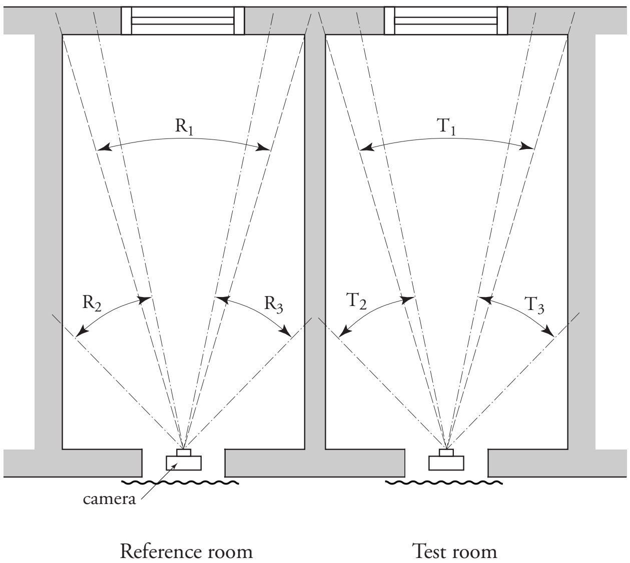



*Figure 2.9 Scheme showing the three pictures taken in each room.*

In order to complete the luminance measurements of the CCD camera and have a reference point to verify the validity of these measurements, an electronic luminance meter LMT Series L 1000 was mounted under the camera to record luminance values at the same time as the camera. The LMT meter can record between 0.0001 and $2 \times 10^7$ cd/m$^2$ and has a spectral sensitivity similar to that of a standard CIE observer. This luminance meter was mounted under the CCD camera on a steel structure specially fabricated for this study. This steel structure was fixed on a rotating support, which was solidly anchored to the door frame as shown in Fig. 2.10.

*Figure 2.10* *Photograph showing the supports for the CCD camera and electronic luminance meter mounted under the camera. The picture also shows the laser beam (top of camera) which was used to adjust the position of the camera (photo Jan Carl Westphall).*

A laser beam was fixed on top of the camera as shown in Fig. 2.10 and small markings were placed on the walls. The position of the camera was adjusted by aligning the laser beam with the markings on the wall. This system ensured that each picture was taken from the same position.

## 2.4 Measurement procedure

Each shading system was evaluated under two extreme sky conditions: a perfectly sunny sky and a totally overcast sky.

### 2.4.1 Sunny sky measurements

The measurements under sunny conditions were carried out between July $2^{nd}$ and $19^{th}$, 2001. Table 2.2 shows when each system was monitored. This table also shows that some measurements were repeated. The repeated measurements are denoted with an apostrophe after the name of the shading system. This convention is used throughout the report.

Each system was monitored three times during a "normal" working day i.e. in the morning between 08.30 and 10.30 hours, at noon between 11.30 and 13.30 hours and in the afternoon between 14.30 and 16.30 hours as shown in Fig. 2.11. The local Danish summer time was used throughout the study since the goal of the study was to evaluate shading devices during normal working hours.

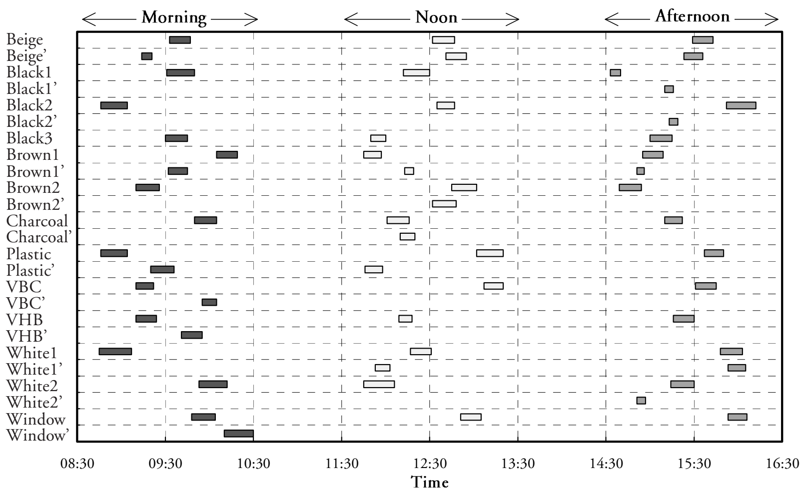



*Figure 2.11 Time of measurement for the sunny sky conditions.*

Table 2.2 Measurement date for the sunny sky conditions.

| # | Period | System | Date | July 2001 | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
| 1 | Morning | Beige | 4-7 2001 | | | | ■ | | | | | | | | | | | | | | | | | |
| 2 | | Beige' | 19-7 2001 | | | | | | | | | | | | | | | | | | | ■ | | |
| 3 | | Black1 | 5-7 2001 | | | | | ■ | | | | | | | | | | | | | | | | |
| 4 | | Black2 | 3-7 2001 | | | ■ | | | | | | | | | | | | | | | | | | |
| 5 | | Black3 | 3-7 2001 | | | ■ | | | | | | | | | | | | | | | | | | |
| 6 | | Brown1 | 4-7 2001 | | | | ■ | | | | | | | | | | | | | | | | | |
| 7 | | Brown1' | 19-7 2001 | | | | | | | | | | | | | | | | | | | ■ | | |
| 8 | | Brown2 | 5-7 2001 | | | | | ■ | | | | | | | | | | | | | | | | |
| 9 | | Charcoal | 4-7 2001 | | | | ■ | | | | | | | | | | | | | | | | | |
| 10 | | Plastic | 5-7 2001 | | | | | ■ | | | | | | | | | | | | | | | | |
| 11 | | Plastic' | 6-7 2001 | | | | | | ■ | | | | | | | | | | | | | | | |
| 12 | | VBC | 4-7 2001 | | | | ■ | | | | | | | | | | | | | | | | | |
| 13 | | VBC' | 6-7 2001 | | | | | | ■ | | | | | | | | | | | | | | | |
| 14 | | VBH | 3-7 2001 | | | ■ | | | | | | | | | | | | | | | | | | |
| 15 | | VBH' | 6-7 2001 | | | | | | ■ | | | | | | | | | | | | | | | |
| 16 | | White1 | 4-7 2001 | | | | ■ | | | | | | | | | | | | | | | | | |
| 17 | | White2 | 5-7 2001 | | | | | ■ | | | | | | | | | | | | | | | | |
| 18 | | Window | 3-7 2001 | | | ■ | | | | | | | | | | | | | | | | | | |
| 19 | | Window' | 5-7 2001 | | | | | ■ | | | | | | | | | | | | | | | | |
| 20 | Noon | Beige | 4-7 2001 | | | | ■ | | | | | | | | | | | | | | | | | |
| 21 | | Beige' | 6-7 2001 | | | | | | ■ | | | | | | | | | | | | | | | |
| 22 | | Black1 | 5-7 2001 | | | | | ■ | | | | | | | | | | | | | | | | |
| 23 | | Black2 | 3-7 2001 | | | ■ | | | | | | | | | | | | | | | | | | |
| 24 | | Black3 | 3-7 2001 | | | ■ | | | | | | | | | | | | | | | | | | |
| 25 | | Brown1 | 4-7 2001 | | | | ■ | | | | | | | | | | | | | | | | | |
| 26 | | Brown1' | 19-7 2001 | | | | | | | | | | | | | | | | | | | ■ | | |
| 27 | | Brown2 | 4-7 2001 | | | | | | | | | | | | | | | | | | | | | |
| 28 | | Brown2' | 5-7 2001 | | | | | ■ | | | | | | | | | | | | | | | | |
| 29 | | Charcoal | 4-7 2001 | | | | ■ | | | | | | | | | | | | | | | | | |
| 30 | | Charcoal' | 6-7 2001 | | | | | | ■ | | | | | | | | | | | | | | | |
| 31 | | Plastic | 5-7 2001 | | | | | ■ | | | | | | | | | | | | | | | | |
| 32 | | Plastic' | 19-7 2001 | | | | | | | | | | | | | | | | | | | ■ | | |
| 33 | | VBC | 3-7 2001 | | | ■ | | | | | | | | | | | | | | | | | | |
| 34 | | VBH | 3-7 2001 | | | ■ | | | | | | | | | | | | | | | | | | |
| 35 | | White1 | 4-7 2001 | | | | ■ | | | | | | | | | | | | | | | | | |
| 36 | | White1' | 6-7 2001 | | | | | | ■ | | | | | | | | | | | | | | | |
| 37 | | White2 | 5-7 2001 | | | | | ■ | | | | | | | | | | | | | | | | |
| 38 | | Window | 3-7 2001 | | | ■ | | | | | | | | | | | | | | | | | | |
| 39 | Afternoon | Beige | 6-7 2001 | | | | | | ■ | | | | | | | | | | | | | | | |
| 40 | | Beige' | 4-7 2001 | | | | ■ | | | | | | | | | | | | | | | | | |
| 41 | | Black1 | 18-7 2001 | | | | | | | | | | | | | | | | | | ■ | | | |
| 42 | | Black1' | 18-7 2001 | | | | | | | | | | | | | | | | | | ■ | | | |
| 43 | | Black2 | 2-7 2001 | | ■ | | | | | | | | | | | | | | | | | | | |
| 44 | | Black2' | 19-7 2001 | | | | | | | | | | | | | | | | | | | ■ | | |
| 45 | | Black3 | 3-7 2001 | | | ■ | | | | | | | | | | | | | | | | | | |
| 46 | | Brown1 | 4-7 2001 | | | | ■ | | | | | | | | | | | | | | | | | |
| 47 | | Brown1' | 18-7 2001 | | | | | | | | | | | | | | | | | | ■ | | | |
| 48 | | Brown2 | 4-7 2001 | | | | ■ | | | | | | | | | | | | | | | | | |
| 49 | | Charcoal | 4-7 2001 | | | | ■ | | | | | | | | | | | | | | | | | |
| 50 | | Plastic | 4-7 2001 | | | | ■ | | | | | | | | | | | | | | | | | |
| 51 | | VBC | 3-7 2001 | | | ■ | | | | | | | | | | | | | | | | | | |
| 52 | | VBH | 3-7 2001 | | | ■ | | | | | | | | | | | | | | | | | | |
| 53 | | White1 | 3-7 2001 | | | ■ | | | | | | | | | | | | | | | | | | |
| 54 | | White1' | 6-7 2001 | | | | | | ■ | | | | | | | | | | | | | | | |
| 55 | | White2 | 2-7 2001 | | ■ | | | | | | | | | | | | | | | | | | | |
| 56 | | White2' | 19-7 2001 | | | | | | | | | | | | | | | | | | | ■ | | |
| 57 | | Window | 4-7 2001 | | | | ■ | | | | | | | | | | | | | | | | | |

Each monitoring period (morning, noon and afternoon) began by adjusting the zero value of all the measuring instruments, including the camera where this is done by taking a "dark current" image. Subsequently, the shading device to be evaluated was placed in the window of both rooms and adjusted to the proper position. The fabric door was then closed to ensure that no light would leak from the corridor. Then the camera, which remained in one of the rooms from the previous measurement period, was adjusted to take the first picture (R1 or T1). This picture was then saved in the computer. The same procedure was repeated for the second (R2 or T2) and third (R3 or T3) pictures. The camera was then moved to the other room and the three pictures were taken and saved in the computer. Care was taken that the doors were properly closed at all time to prevent light leakage into the rooms, except when the experimenter was manipulating the camera. Once the six pictures were taken, the experimenter went to the Reference room and measured the luminance of the sky seen through the window-shade combination, the luminance of the sunlight patches in the room as well as the luminance of the sky through the window (without the shading device). These luminance values as well as the position of the sunlight patches were carefully noted in a lab book. The experimenter then went to the Test room, sat on the chair facing the window and filled a questionnaire about the visual comfort in the room, adding comments when necessary. The same procedure was repeated for each shading system. It took between five and 22 minutes to complete one test.

### 2.4.2 Overcast sky measurements

The overcast day measurements were made in order to determine the daylight factor. These measurements were thus limited to recording the horizontal illuminance under overcast conditions. The exact time when these measurements were made did not really matter as long as the luminance distribution of the sky did correspond to the definition of an overcast sky i.e. the ratio between the vertical illuminance on the facade and the global illuminance must be 0.396. In this case, ratios between 0.36 and 0.44 were judged acceptable as well. The measurements thus basically consisted of leaving the shading devices in the window during a certain period of time on an overcast day and letting the lux meters record the illuminance values every 30 seconds during that period.

## 2.5 Data analysis

The measurements under sunny conditions added up to 39 tests (13 alternatives, three times a day). Eighteen tests were repeated in order to make sure that results were replicable. Thus, a total of 57 tests were performed under sunny conditions as shown in Table 2.2.

The first step of the data analysis consisted of comparing the illuminance and luminance values obtained during the first and second test. The second step consisted of comparing luminance readings obtained with the CCD camera with the ones obtained with the electronic (LMT) and manual (Hagner) luminance meters. Finally, the third step consisted of comparing the vertical illuminance values recorded by the lux meters with the luminance values measured by the CCD camera around the same point.

Some tests were eliminated from the analysis either because the readings by two instruments did not correlate or because the first and second tests differed by more than 15 %. Table 2.3 shows which tests were eliminated and the reason for this elimination.

Table 2.3 shows that a poor correlation between luminance readings occurred most often for the first picture (R1 and T1), and between the electronic luminance meter and the camera. This is due to the fact that, for this particular picture, the electronic luminance meter was measuring a point falling somewhere in a group of trees in front of the laboratory. Since there was a great variation in luminance in that region of the scene, it is most likely that even a small error in positioning the camera or the spot on the digital image might have resulted in large differences in the luminance value recorded. This is illustrated in Fig. 2.12. This figure shows that a small error in positioning the spot on the digital image can result in a large difference in the luminance value. In this case, the first spot (A) has a luminance of 1056.55 cd/m$^2$, while the second spot (B) has a luminance value of 678.19 cd/m$^2$, a relative difference of around 36 %.

Table 2.3 List of the shading devices showing which tests were eliminated from the data analysis and the reason for this elimination.

| # | Period | System | Date | Picture R1 | R2 | R3 | T1 | T2 | T3 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Morning | Beige | 4-7 2001 | | | | 1 | | |
| 2 | | ~~Beige'~~ | ~~19-7 2001~~ | | | | 1 | | |
| 3 | | Black1 | 5-7 2001 | | | | | | |
| 4 | | Black2 | 3-7 2001 | | | | | 2 | |
| 5 | | Black3 | 3-7 2001 | | | | | | |
| 6 | | Brown1 | 4-7 2001 | 2 | | 2 | 2 | | |
| 7 | | ~~Brown1'~~ | ~~19-7 2001~~ | | | | | | |
| 8 | | Brown2 | 5-7 2001 | | | | | | |
| 9 | | Charcoal | 4-7 2001 | | | | | | |
| 10 | | ~~Plastic~~ | ~~5-7 2001~~ | 1 | | | | | |
| 11 | | Plastic' | 6-7 2001 | | | | | | |
| 12 | | ~~VBC~~ | ~~4-7 2001~~ | | | M | | 2 | |
| 13 | | VBC' | 6-7 2001 | | | | | | |
| 14 | | VBH | 3-7 2001 | | | | | 2 | |
| 15 | | VBH' | 6-7 2001 | | | | | 2 | |
| 16 | | White1 | 4-7 2001 | 1 | | | 2 | | |
| 17 | | White2 | 5-7 2001 | | | | 1 | 2 | |
| 18 | | Window | 3-7 2001 | 2 | | | 2 | 2 | |
| 19 | | ~~Window'~~ | ~~5-7 2001~~ | | | | | | |
| 20 | Noon | Beige | 4-7 2001 | 2 | | | 2 | | |
| 21 | | Beige' | 6-7 2001 | 2 | | | 2 | | |
| 22 | | Black1 | 5-7 2001 | | | | | 2 | |
| 23 | | Black2 | 3-7 2001 | | | | | 2 | |
| 24 | | Black3 | 3-7 2001 | | | | | | |
| 25 | | Brown1 | 4-7 2001 | 2 | | | 2 | | |
| 26 | | Brown1' | 19-7 2001 | | | | | | |
| 27 | | Brown2 | 4-7 2001 | 2 | | | 2 | | |
| 28 | | Brown2' | 5-7 2001 | 2 | | | 1, 2 | | |
| 29 | | ~~Charcoal~~ | ~~4-7 2001~~ | | | | | | |
| 30 | | Charcoal' | 6-7 2001 | | | | | | |
| 31 | | ~~Plastic~~ | ~~5-7 2001~~ | 1, 2 | | | 2 | | M |
| 32 | | Plastic' | 19-7 2001 | | | | 2 | | |
| 33 | | VBC | 3-7 2001 | | 2 | 2 | | | 2 |
| 34 | | VBH | 3-7 2001 | 2 | | | | | |
| 35 | | White1 | 4-7 2001 | | | | | | |
| 36 | | White1' | 6-7 2001 | | | | | | |
| 37 | | White2 | 5-7 2001 | | | | | | |
| 38 | | Window | 3-7 2001 | | | | | | |
| 39 | Afternoon | Beige | 6-7 2001 | | | | 2 | | |
| 40 | | ~~Beige'~~ | ~~4-7 2001~~ | 2 | | | | | |
| 41 | | Black1 | 18-7 2001 | | | | | | |
| 42 | | ~~Black1'~~ | ~~18-7 2001~~ | 2 | | | 2 | 2 | |
| 43 | | Black2 | 2-7 2001 | 2 | | | 2 | 2 | |
| 44 | | Black2' | 19-7 2001 | 2 | | | 2 | | |
| 45 | | Black3 | 3-7 2001 | 2 | | | 2 | | |
| 46 | | ~~Brown1~~ | ~~4-7 2001~~ | 2 | | M | 2 | | |
| 47 | | Brown1' | 18-7 2001 | | | | | | |
| 48 | | Brown2 | 4-7 2001 | 2 | | | 2 | | |
| 49 | | Charcoal | 4-7 2001 | 2 | | | 2 | | |
| 50 | | Plastic | 4-7 2001 | 1 | | | 1, 2 | | |
| 51 | | VBC | 3-7 2001 | 2 | 2 | 2 | | 2 | |
| 52 | | VBH | 3-7 2001 | | | | | | |
| 53 | | ~~White1~~ | ~~3-7 2001~~ | 1 | 2 | 2 | 1 | 2 | 2 |
| 54 | | ~~White1'~~ | ~~6-7 2001~~ | | | | | 2 | |
| 55 | | ~~White2~~ | ~~2-7 2001~~ | | 2 | 1 | | | |
| 56 | | White2' | 19-7 2001 | | | | | | |
| 57 | | Window | 4-7 2001 | 2 | 2 | | 2 | | 2 |

| | |
|---|---|
| (light grey) | Luminance values differed by more than 15% |
| (dark grey) | Illuminance values differed by more than 15% |
| 1 | IQcam and Hagner readings did not correlate |
| 2 | IQcam and LMT readings did not correlate |
| M | IQcam picture was missing |
| (hatched) | Vertical illuminance and IQcam readings did not correlate. |

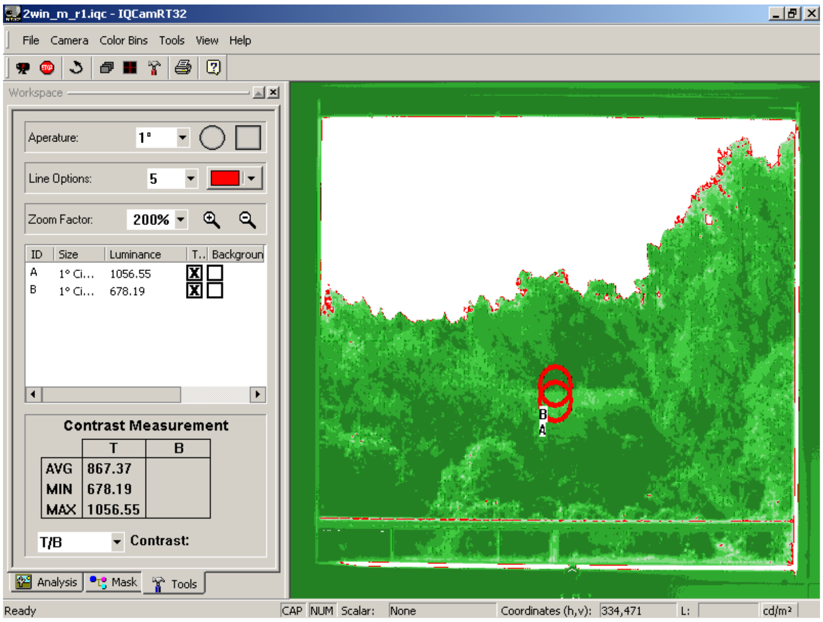



*Figure 2.12* *Picture R1 showing the position of the spot measured by the electronic luminance meter. The picture shows that this spot falls in a group of trees in front of the laboratory and that a small error in positioning the camera results in large differences in luminance value.*

Note also that there was a poor correlation between the electronic luminance meter and the camera for picture T2 because the point that the electronic luminance meter recorded fell on a dark piece of furniture (a shelf) in the test room. This point often had a luminance value outside the dynamic range of the camera, which affected the precision of the camera. Fig. 2.13 shows the picture T2 and the position of the electronic luminance meter reading point.

Among the 57 tests performed, three tests (VBC, morning; Plastic, noon; Brown1, afternoon) were eliminated from the analysis because one of the six pictures was missing. The experimenter simply forgot to save the picture during the measurements.

Moreover, two tests (Brown1', morning; Window', morning) were eliminated because the illuminance values of the first and second tests differed by more than 15 %. An examination of the weather conditions during the measurements revealed that one of the tests was performed under a partly covered (> 50 %) sky, which probably resulted in a different sky luminance distribution as well as a different light distribution in the room.

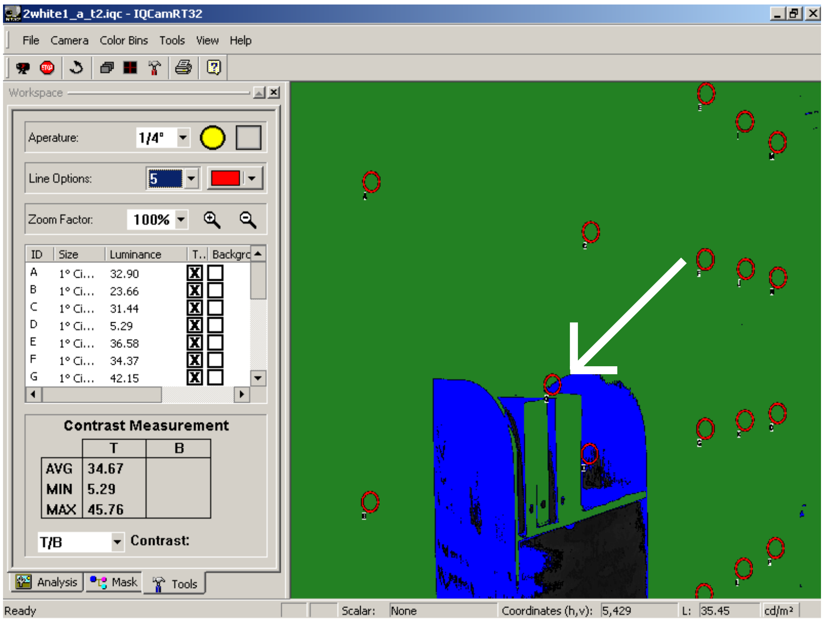



*Figure 2.13* *Picture T2 showing the position of the spot measured by the electronic luminance meter. The picture shows that this spot falls on a dark piece of furniture which often had a luminance outside the dynamic range of the CCD camera.*

Finally, eight tests (Beige', morning; Plastic, morning; Charcoal, noon; Beige', afternoon; Black1', afternoon; White1 and White1', afternoon; White2, afternoon) were eliminated because the difference between the readings from the electronic (LMT) or manual (Hagner) luminance meter and the camera differed by more than 15 % plus that the luminance values of the first and second tests differed by more than 15 % for some pictures. In two cases (Beige', morning and White2, afternoon), we suspect that the differences between the first and second tests were due to the fact that the second test was performed much later (over 15 days) than the first test. In the case of the Plastic screen, the difference was attributed to a small shift in the position of the camera with respect to the luminance meter. Since this screen has an irregular weave pattern, a small shift in positioning the camera or luminance meter might have resulted in large differences in luminance values. In two cases (White1 and White1', afternoon), there was poor correlation between the camera and both luminance meter readings as well as poor correlation between the camera and the vertical lux meters readings. Moreover, the luminance values of the first and second tests differed by more than 15 %. An examination of the lab book revealed that one of these tests (White1', afternoon) was performed during a period when the camera had an unstable behaviour. During that period of measurements, the experimenter discovered that one of the cables connecting the camera to the computer became warm after many hours of use, which was due to a short circuit in the cable. The cable was immediately repaired and the problem did not recur. Both tests (White1 and White1', afternoon) were judged inadequate and were removed from the analysis.

Among the remaining 44 tests, a high degree of replicability was found between the first and second test with a maximum relative difference of 15 % in illuminance and luminance readings. Also, it was found that the readings from the camera correlated well with the ones from both luminance meters (see Appendix A and B). The vertical illuminance values also correlated with the luminance spot readings of the camera (see Appendix C), which is an indication that the readings of the camera were correct.

In the final analysis, only the test for which the readings of the camera had the highest degree of correlation with the electronic and manual luminance meter readings and the vertical illuminance meter readings were considered in the analysis. Since the repeated test was not carried out at exactly the same time and on the same day as the first test, taking a simple average between the two tests gave funny values in some cases (the sunlight patch was not exactly at the same place in the room). Thus, the repeated test was left out of the analysis even if it showed an acceptable degree of replicability with respect to the first test.

# 3 Results

## 3.1 Exterior illuminance

The global horizontal and vertical illuminance were recorded continuously during the tests. Although the measurements were performed at more or less the same time and during more or less the same period of the year, there were substantial differences in exterior global and vertical illuminance. The values obtained are shown in Fig. 3.1 to 3.3.

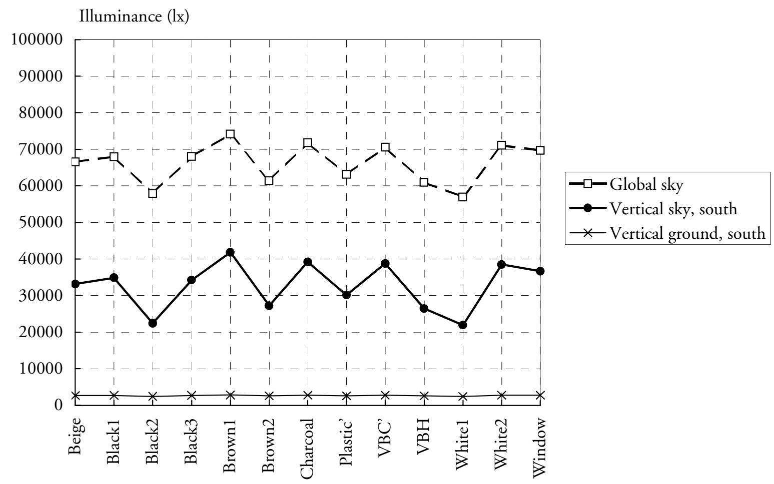



*Figure 3.1 Global illuminance (lx) and vertical illuminance (lx) on the south facade from the sky and ground for the morning measurements.*

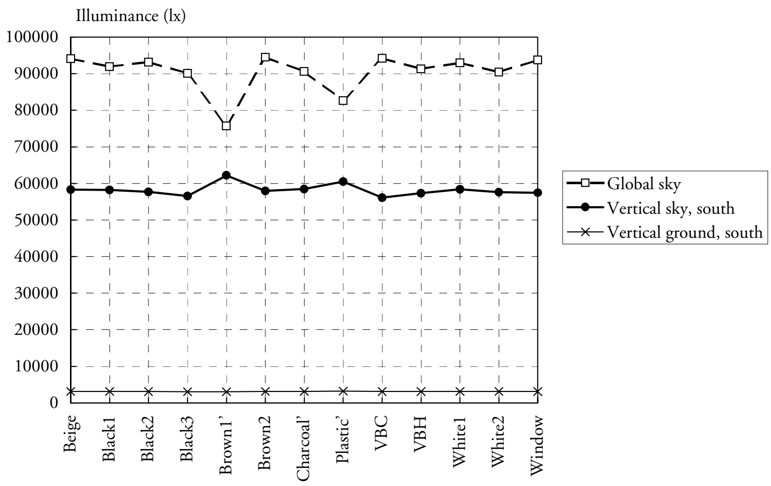



*Figure 3.2* *Global illuminance (lx) and vertical illuminance (lx) on the south facade from the sky and ground for the noon measurements.*

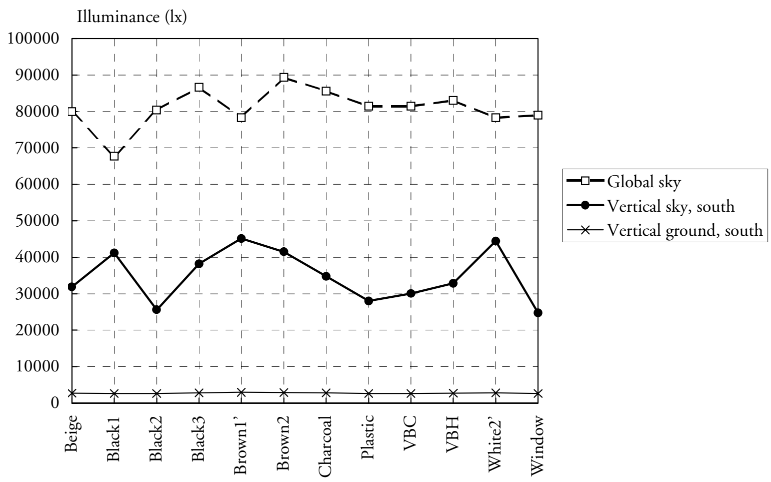



*Figure 3.3* *Global illuminance (lx) and vertical illuminance (lx) on the south facade from the sky and ground for the afternoon measurements.*

Fig. 3.1 to 3.3 show that lower illuminance values were recorded in the morning than at noon and in the afternoon. Also, as expected, the noon measurements recorded the highest values. The vertical illuminance from the ground was fairly constant throughout the day and for all the shading systems tested. The vertical illuminance on the facade from the sky varied significantly between measurements, especially in the morning and in the afternoon. In the morning, the vertical illuminance varied roughly between 20 and 40 klx and in the afternoon, it varied between 25 and 45 klx. The vertical illuminance was fairly constant at noon time. In the morning, the curve of the vertical illuminance (sky) more or less followed that of the global illuminance. This is also the case at noon and in the afternoon except for Brown1' (noon), Plastic' (noon), Black1 (afternoon), Brown1' (afternoon) and White2' (afternoon). In these cases, the global to vertical illuminance ratio was different from that for the other shading systems. An examination of the lab book revealed that these measurements were performed on July 18-19$^{th}$, a period with some cloud cover on the North sky hemisphere. Thus, the sky luminance distribution might have been slightly different in those cases, which might have affected the global to vertical illuminance ratio.

## 3.2 Absolute work plane illuminance

The illuminance on the work plane was continuously recorded every 30 seconds at ten points in the Reference room and sex points in the Test room. The results of the measurements in the Reference room are shown in Fig. 3.4 to 3.6.

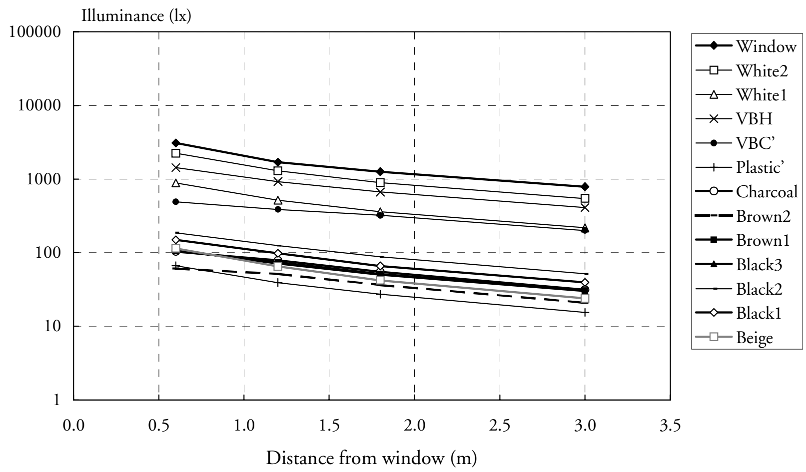



*Figure 3.4* *Work plane illuminance (lx) as a function of distance from the window for the central row of detectors (A1-A4) in the Reference room, morning measurements.*

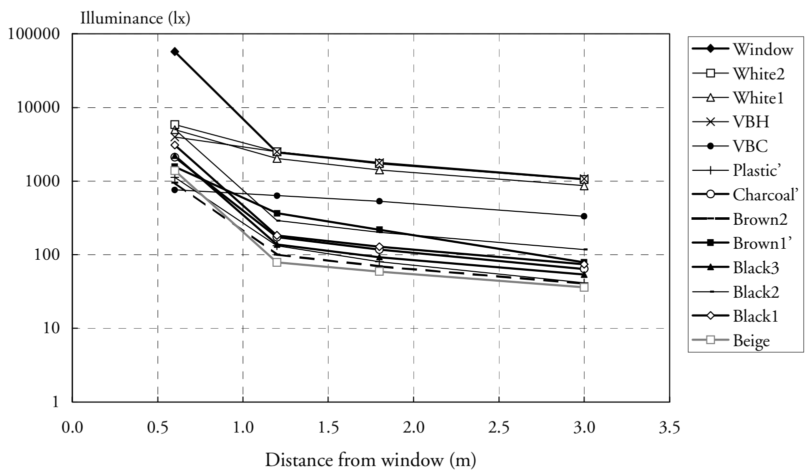



*Figure 3.5* *Work plane illuminance (lx) as a function of distance from the window for the central row of detectors (A1-A4) in the Reference room, noon measurements.*

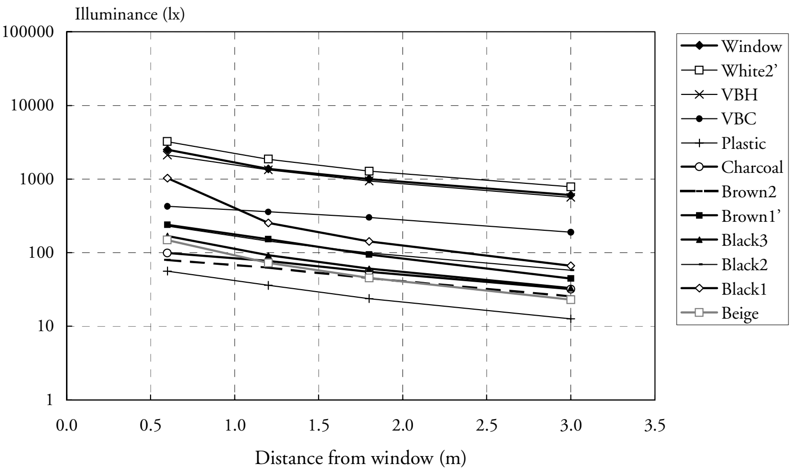



*Figure 3.6* *Work plane illuminance (lx) as a function of distance from the window for the central row of detectors (A1-A4) in the Reference room, afternoon measurements.*

Fig. 3.4 (morning measurements) shows that the shading systems can be divided into two groups: a group (Beige, Black1-2-3, Brown1-2, Charcoal, Plastic') with illuminance values below 200 lx and a group (VBC', VBH, White1-2, Window) with medium to high illuminance values (200-3000 lx). The illuminance profile is similar for all systems and follows more or less a straight line on the logarithmic scale. The only exceptions are the systems VBC' and Brown2, which have a slightly flatter curve indicating that light was more evenly distributed in the room.

At noon time, Fig. 3.5 indicates that some systems created a bright sunlight patch close to the window since the illuminance profile followed almost exactly that of the bare window. This is the case for most shading systems tested except for White1-2 and VBC'. The white screens were very diffusing and thus prevented sunlight patches.

During the afternoon (Fig. 3.6), the illuminance profile was similar to the morning profiles and the shading systems can also be divided into two groups as in the morning, although the distinction is not as clear. VBC generally had a higher illuminance than the other shading systems and, as in the morning, its curve was flatter. The same can be said about the curves from the screens Brown2 and Charcoal while Black1 produced more light close to the window. However, the exterior vertical illuminance was rather high for this system as shown in Fig. 3.3.

The screen White2' resulted in higher illuminance values than the bare window. This is probably due to the fact that the illuminance on the facade was higher for this case than for the bare window. This is illustrated by Fig. 3.7, which shows the global and vertical illuminance on the south facade from the sky and ground as well as the average illuminance in the room as a function of shading system. This figure shows that if we multiply the average illuminance by a factor proportional to the vertical illuminance (from the sky), the average illuminance of the screen White2' is less than the average illuminance of the bare window case.

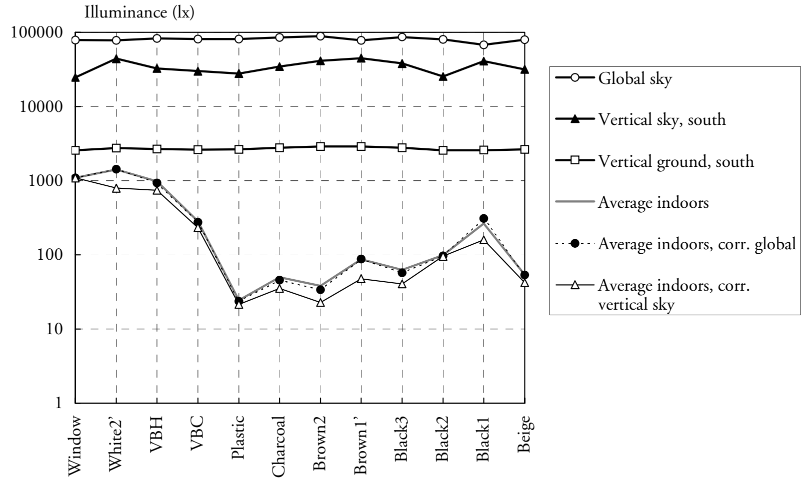



*Figure 3.7* *Global and vertical illuminance (lx) from the sky and ground, and average indoor illuminance (lx) corrected as a function of the global illuminance (Average indoors, corr. global) and the vertical illuminance from the sky (Average indoors, corr. vertical sky).*

The illuminance profiles for the Test room are shown in Fig. 3.8 to 3.10 for the central row of detectors (B1-B6). Note that in this case the detectors cover the full depth of the room.

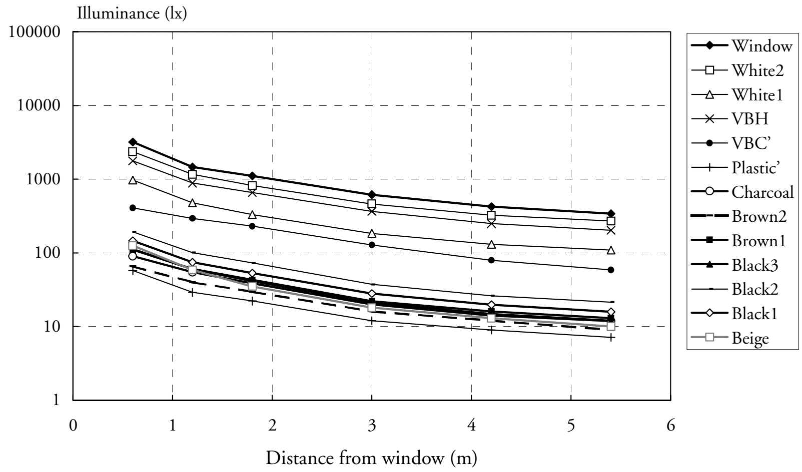



*Figure 3.8* *Work plane illuminance (lx) as a function of distance from the window for the central row of detectors (B1-B6) in the Test room, morning measurements.*

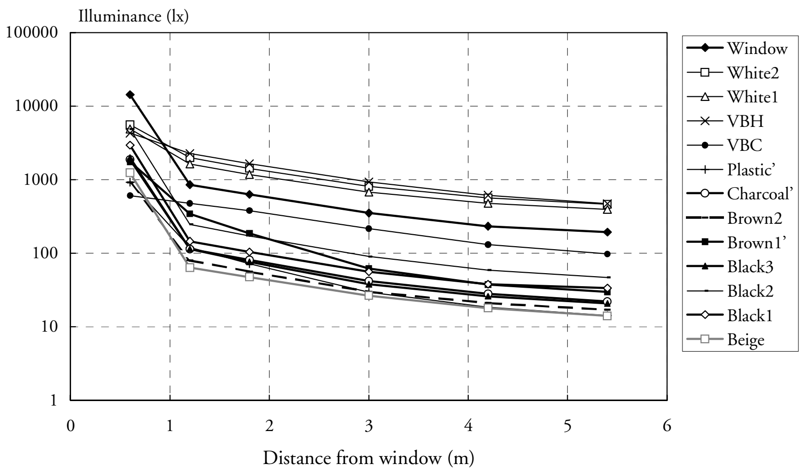



*Figure 3.9* *Work plane illuminance (lx) as a function of distance from the window for the central row of detectors (B1-B6) in the Test room, noon measurements.*

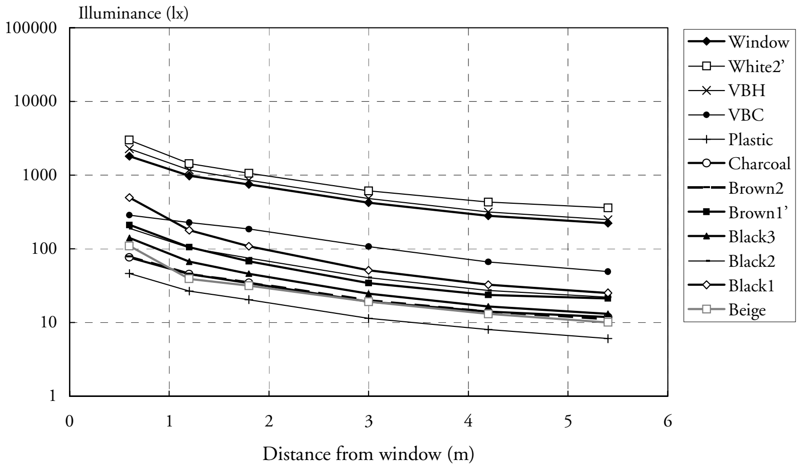



*Figure 3.10* *Work plane illuminance (lx) as a function of distance from the window for the central row of detectors (B1-B6) in the Test room, afternoon measurements.*

The same comments can be made about the illuminance profiles in the Test room as shown by Fig. 3.8 to 3.10. At noon time (Fig. 3.9), the illuminance for the bare window was somewhat lower in the Test room than in the Reference room . This is due to the fact that the direct sunlight patch fell somewhere between the desk and the window and the desk thus shaded this bright light patch from the rest of the room. Less light was thus reflected towards the ceiling and walls, which reduced the intensity of the internally reflected light component.

In general, the illuminance values were lower in the Test room than in the Reference room by around 23 %, if we compare the values obtained for detectors A2-A4 (Reference room) and B2-B4 (Test room). However, the difference for the detector closest to the window (A1, B1) was not as systematic. In some cases, the illuminance was higher in the Test room than in the Reference room. This aspect is discussed in detail in Appendix D.

Fig. 3.11 to 3.13 show the percentage of points for which a given illuminance value was exceeded in the Reference room.

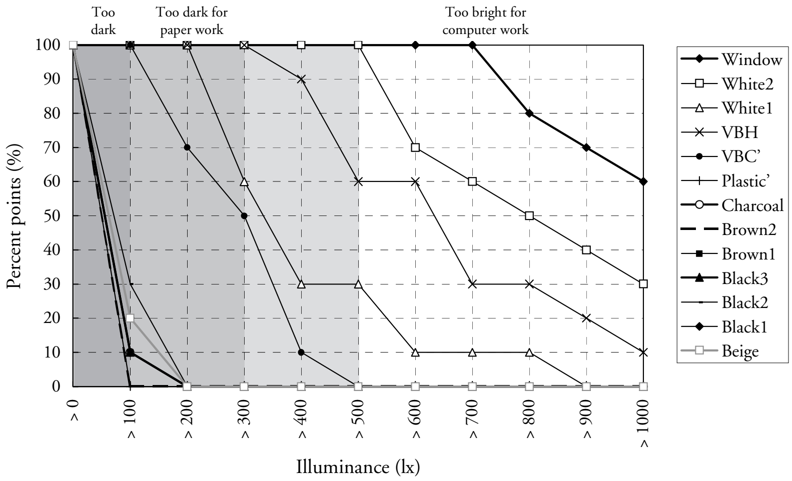



*Figure 3.11* *Percentage (%) of measured points for which the illuminance exceeded a given value in the Reference room, morning measurements.*

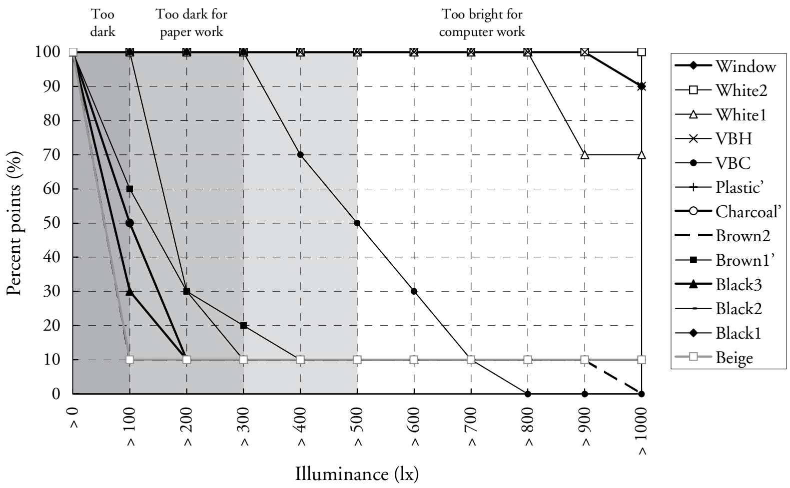



*Figure 3.12* *Percentage (%) of measured points for which the illuminance exceeded a given value in the Reference room, noon measurements.*

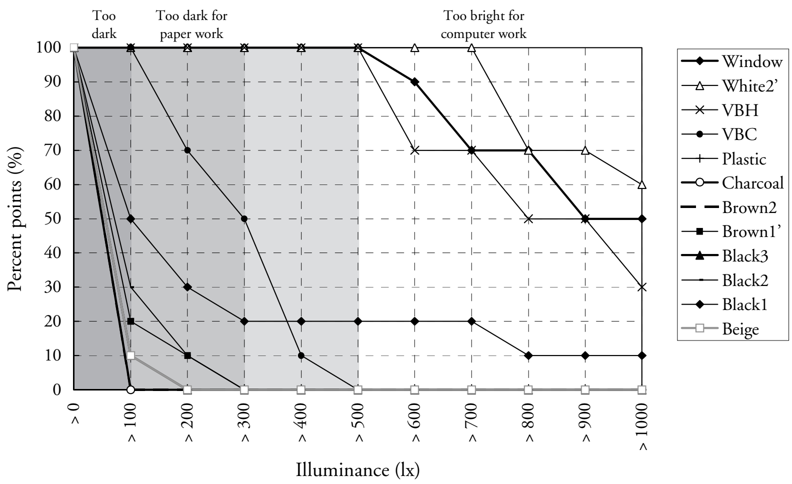



*Figure 3.13* *Percentage (%) of measured points for which the illuminance exceeded a given value in the Reference room, afternoon measurements.*

Fig. 3.11 to 3.13 show that for the white screens (White1-2), VBH and the bare window, the majority of points received over 500 lx. These solutions are thus ideal for paper work but might be too bright for work on computers. VBC provided an illuminance range which is suitable for a combination of paper and computer work, while the other screens were all too dark since the majority of the points recorded illuminance values below 100 lx. However, the screens Brown1, Black1-2-3 and Charcoal may provide enough light for computer work at noon time. Black1 may even provide enough light for computer work during the afternoon, although the high values obtained may be attributed to the particularly high exterior illuminance levels on the facade which occurred for this case as shown in Fig. 3.3.

The results obtained in the Reference room are summarised in Table 3.1.

Table 3.1 Percentage (%) of points above or below specific illuminance values and corresponding interpretation, for the Reference room.

A= Too dark for computer and paper work
B= Too dark for paper work
C= Too bright for computer work

| | | Percent point (%) below or above a given illuminance | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| System | Period | < 100 lx | < 300 lx | < 500 lx | > 500 lx | More suitable for: | Other comments: | | |
| Beige | morning | 80 | 100 | 100 | 0 | None | A | B | |
| Black1 | morning | 80 | 100 | 100 | 0 | None | A | B | |
| Black2 | morning | 70 | 100 | 100 | 0 | None | A | B | |
| Black3 | morning | 90 | 100 | 100 | 0 | None | A | B | |
| Brown1 | morning | 90 | 100 | 100 | 0 | None | A | B | |
| Brown2 | morning | 100 | 100 | 100 | 0 | None | A | B | |
| Charcoal | morning | 90 | 100 | 100 | 0 | None | A | B | |
| Plastic' | morning | 100 | 100 | 100 | 0 | None | A | B | |
| VBC' | morning | 0 | 50 | 100 | 0 | Paper+Computer work | | | |
| VBH | morning | 0 | 0 | 40 | 60 | Paper work | | | C |
| White1 | morning | 0 | 40 | 70 | 30 | Paper+Computer work | | | |
| White2 | morning | 0 | 0 | 0 | 100 | Paper work | | | C |
| Window | morning | 0 | 0 | 0 | 100 | Paper work | | | C |
| Beige | noon | 90 | 90 | 90 | 10 | None | A | B | |
| Black1 | noon | 50 | 90 | 90 | 10 | Computer work | | B | |
| Black2 | noon | 0 | 90 | 90 | 10 | Computer work | | B | |
| Black3 | noon | 70 | 90 | 90 | 10 | None | A | B | |
| Brown1' | noon | 40 | 80 | 90 | 10 | Computer work | | B | |
| Brown2 | noon | 80 | 90 | 90 | 10 | None | A | B | |
| Charcoal' | noon | 50 | 90 | 90 | 10 | Computer work | | B | |
| Plastic' | noon | 70 | 90 | 90 | 10 | None | A | B | |
| VBC | noon | 0 | 0 | 50 | 50 | Paper+Computer work | | | |
| VBH | noon | 0 | 0 | 0 | 100 | Paper work | | | C |
| White1 | noon | 0 | 0 | 0 | 100 | Paper work | | | C |
| White2 | noon | 0 | 0 | 0 | 100 | Paper work | | | C |
| Window | noon | 0 | 0 | 0 | 100 | Paper work | | | C |
| Beige | afternoon | 90 | 100 | 100 | 0 | None | A | B | |
| Black1 | afternoon | 50 | 80 | 80 | 20 | Computer work | | B | |
| Black2 | afternoon | 70 | 100 | 100 | 0 | None | A | B | |
| Black3 | afternoon | 90 | 100 | 100 | 0 | None | A | B | |
| Brown1' | afternoon | 80 | 100 | 100 | 0 | None | A | B | |
| Brown2 | afternoon | 100 | 100 | 100 | 0 | None | A | B | |
| Charcoal | afternoon | 100 | 100 | 100 | 0 | None | A | B | |
| Plastic | afternoon | 100 | 100 | 100 | 0 | None | A | B | |
| VBC | afternoon | 0 | 50 | 100 | 0 | Paper+Computer work | | | |
| VBH | afternoon | 0 | 0 | 0 | 100 | Paper work | | | C |
| White2' | afternoon | 0 | 0 | 0 | 100 | Paper work | | | C |
| Window | afternoon | 0 | 0 | 0 | 100 | Paper work | | | C |

## 3.3 Daylight factor

The daylight factor (*D*) was studied to see how the shading devices affected indoor lighting levels under overcast conditions. Many standards also have requirements regarding the *D*. In general, it is demanded that the *D* be above 1 % but 2-3 % is more desirable as it will provide 200-300 lx of illuminance when the outdoor global illuminance is 10 000 lx. A *D* of 5

% ensures total daylight autonomy (no need for artificial lighting) since it corresponds to an indoor illumination of 500 lux with an outdoor illumination of 10 000 lux.

The *D* was calculated from measurements under overcast conditions performed during the period July-August 2001. At the time of writing this report, only a part of the measurements were completed. The *D* for the shading systems not appearing in this report will be presented in a future publication. Fig. 3.14 and 3.15 show the results obtained for the Reference and Test rooms. The profiles of the Reference room appear incomplete because there was no lux meter at the back of the room.

Fig. 3.14 and 3.15 show that the *D* profiles are approximately similar for the Reference and Test rooms although the values in the Test room are somewhat lower, which was expected. Again, the shading systems can be divided into two groups: White1-2 where the *D* is between 0.25 and 3.0 % and the rest of the shading devices, which have a *D* below 0.75 %. Black2 is somewhat better with a *D* around 1.5 % close to the window.

The average *D* for detectors A1-A4 and B1-B4 in the Reference and Test rooms as well as the average *D* for all the detectors in each room (A1-A10, B1-B6) are shown in Fig. 3.16. This figure also shows the *D* for the point in the middle of each room (Ref_middle, Test_middle).

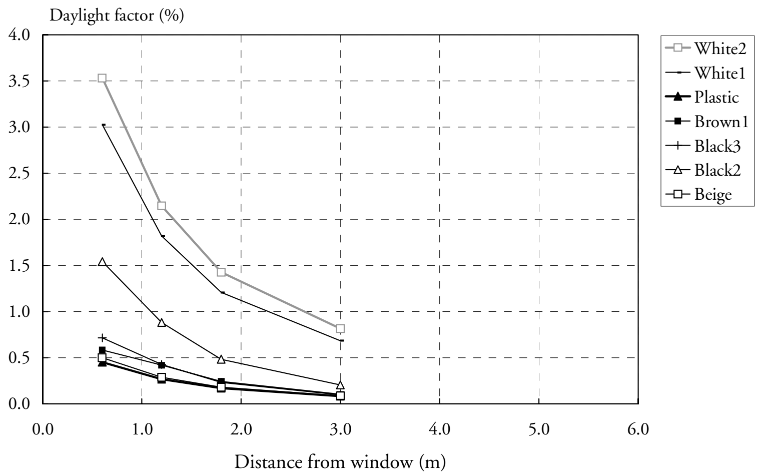



*Figure 3.14 Daylight factor (%), detectors A1-A4, in the Reference room.*

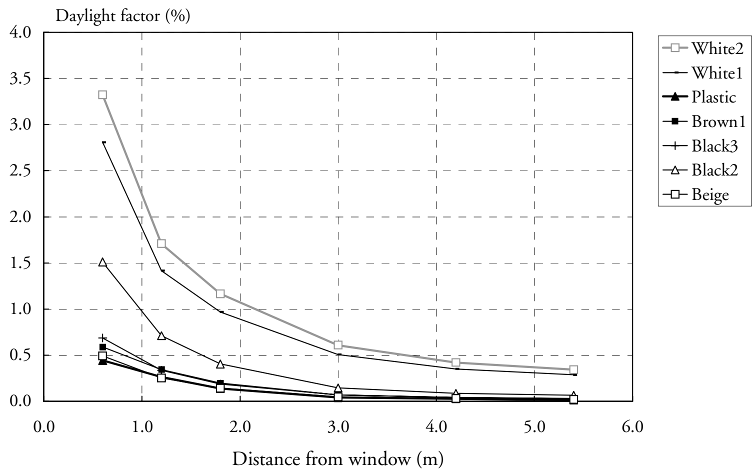



*Figure 3.15* *Daylight factor (%), detectors B1-B6, in the Test room.*

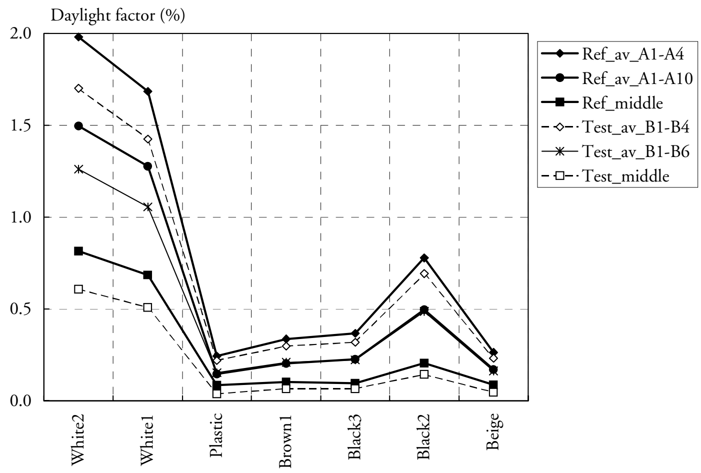



*Figure 3.16* *Average D in the Reference and Test rooms for detectors A1-A4 (Ref_av_A1-A4) and B1-B4 (Test_av_B1-B4) and for all the detectors in the room (Ref_av_A1-A10, Test_av_B1-B6) and D in the middle of the room (Ref_middle, Test_middle).*

Fig. 3.16 shows that the screens Plastic, Brown1, Black3 and Beige have *D*s well below 0.5 %, which is unacceptably low. Among these systems, Beige and Plastic are the worst. Black2 is somewhat better with an average *D* of 0.75 % for detectors A1-A4 and B1-B4, but this value is still very low. On the brighter side, the screens White1-2 provide more light with an average *D* above 1 %, in both rooms. The values close to the window were even quite good (between 1.5 and 2.0 %) for the screen White2 and the middle point had a *D* between 0.5 and 1.0 % in both rooms.

The values of the detectors B1-B4 (Test room) were on average around 12 % lower than the values of the corresponding detectors (A1-A4) in the Reference room. The difference between the two rooms was larger for the middle point, with a value that was 35 % lower on average in the Test room than in the Reference room.

## 3.4 Illuminance uniformity on the work plane

The illuminance uniformity on the work plane is one determinant of lighting quality in a work space since large contrasts on the desk can result in discomfort glare and visual fatigue. This aspect was analysed by studying the ratios between work plane illuminance values of any two adjacent points in the Reference room. A total of 18 illuminance ratios were studied (Fig. 3.17), which corresponds to as many possible desk positions in the space.

Fig. 3.18 shows the percentage of ratios studied which met the requirements expressed in Table 1.1. Fig. 3.18 shows that the less severe requirement ($E_{min}/E_{max} > 0.5$) was met by the majority (60-80 %) of the ratios for all the shading systems. VBC had a better performance with 100 % of the ratios meeting this requirement. In the case of the more severe requirements ($E_{min}/E_{max} > 0.7$, $E_{min}/E_{av} > 0.8$), the percentage of ratios which met the requirements was only around 40-50 % for most systems except VBC, which also performed better with nearly 65 % of the ratios meeting the requirements. The results thus indicate that the illuminance was more evenly distributed with the closed venetian blind (VBC).

This analysis shows that it is difficult to meet the more severe requirements since only one shading system (VBC) “passed the test”. However, the distance between the illuminance points was relatively large in this case, which might explain why the more severe requirements were not met in most cases. The results also show that there are no significant differences among all shading systems except VBC, which performed significantly better than the other systems. Finally, the analysis shows that there is little difference between the two more severe requirements since they result in approximately the same number of ratios which meet the requirements.

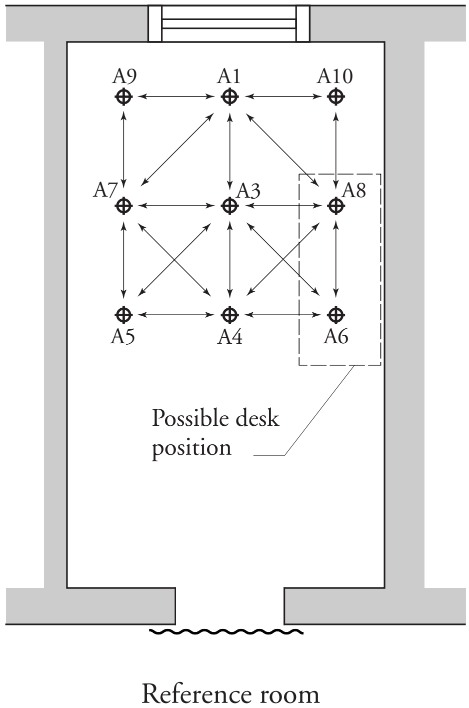



*Figure 3.17 Illuminance ratios studied in the Reference room.*

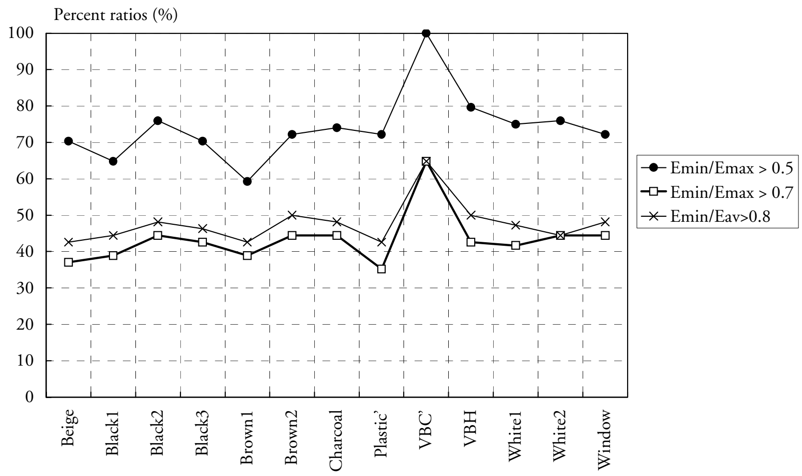



*Figure 3.18* *Percentage (%) of illuminance ratios meeting the requirements expressed in Table 1.1, Reference room.*

# 3.5 Absolute vertical luminance

## 3.5.1 Maximum luminance

The luminance of the walls and window was recorded with the CCD camera and two luminance meters. Although the digital images from the CCD camera provide over one million luminance values for each picture, the analysis was limited to studying the luminance at specific "spots", which were repeatedly placed on each picture with the help of the analysis program provided with the camera. These spots were regularly distributed along the walls as illustrated in Fig. 3.19. Fig. 3.20 shows how the spots were placed on the picture with the help of the analysis program.

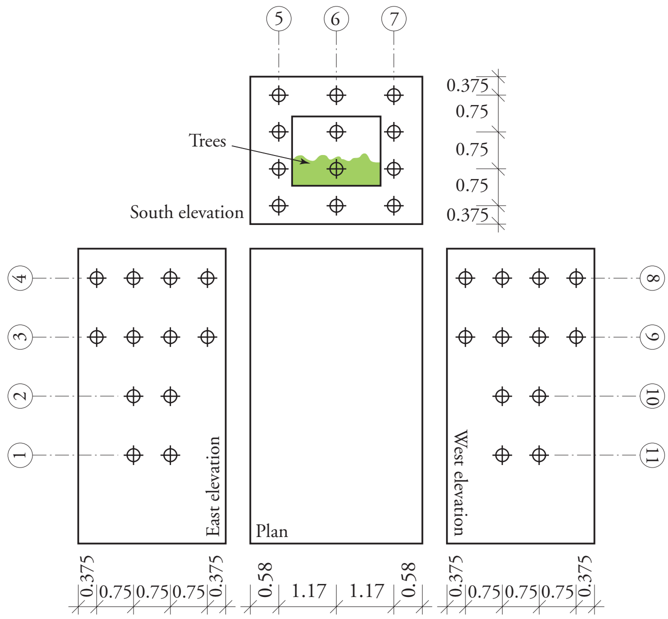
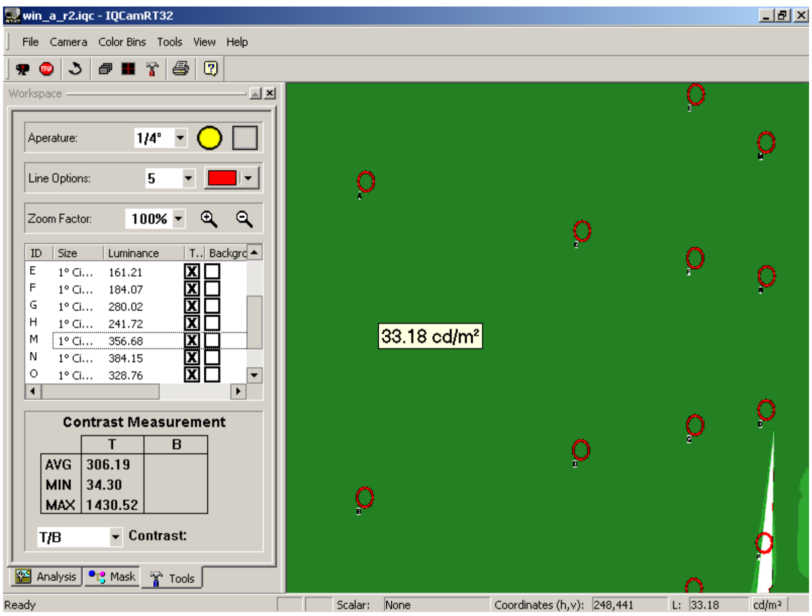
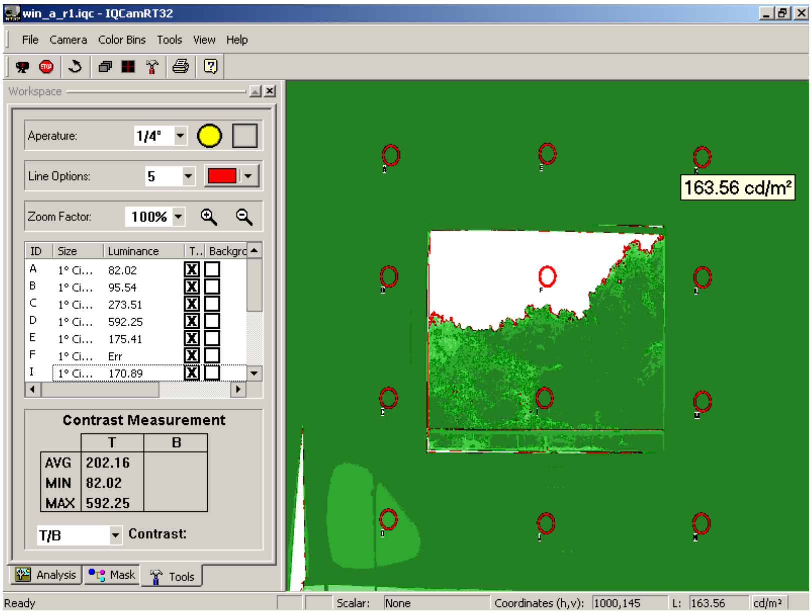


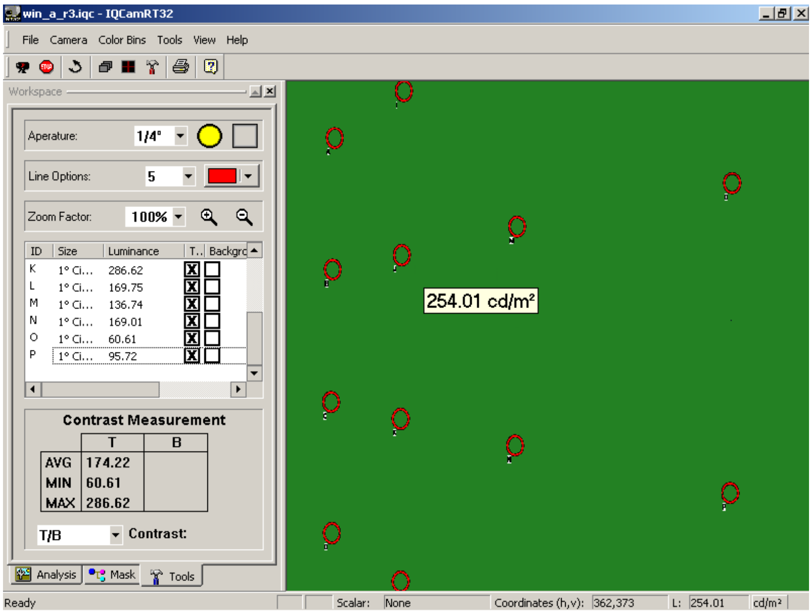

*Figure 3.19 Position of the spots on the walls and windows.*




a)




b)




c)

*Figure 3.20* *Picture showing how the spots are placed on the digital pictures a) R2, b) R1 and c) R3 with the help of the analysis program provided with the camera.*

The spots' luminance values for a given height from the floor are plotted in Fig. 3.21 to 3.24 for the morning measurements, in the Reference room.

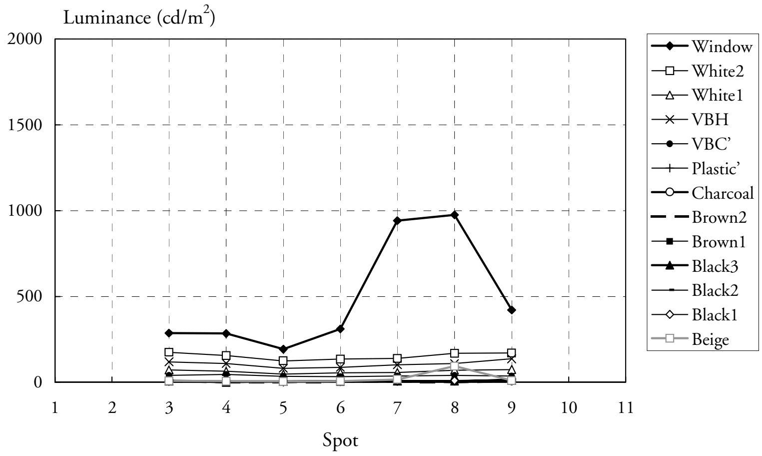



*Figure 3.21* *Luminance values (cd/m²) obtained for each spot at 0.375 m from the floor for the morning measurements, in the Reference room.*

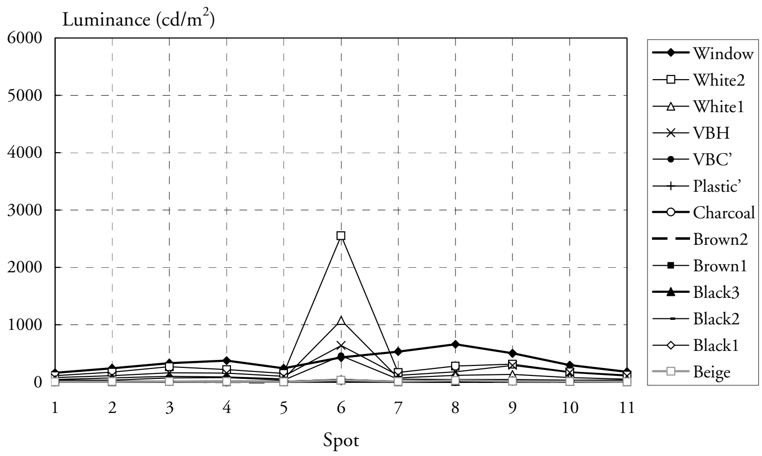



*Figure 3.22* *Luminance values (cd/m²) obtained for each spot at 1.125 m from the floor for the morning measurements, in the Reference room.*

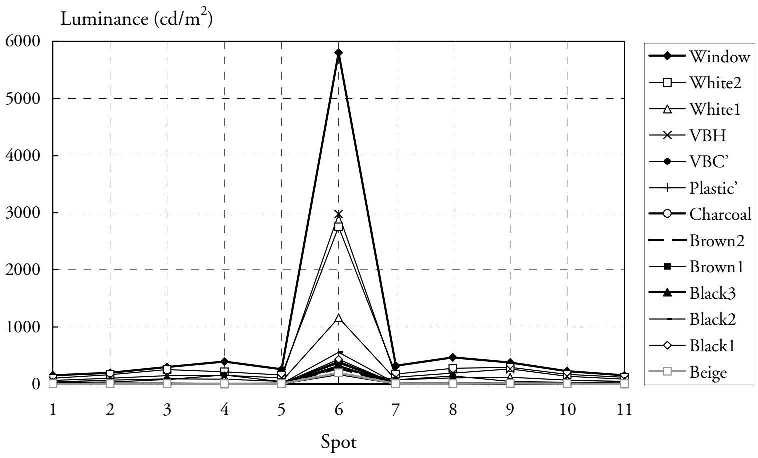



*Figure 3.23* *Luminance values (cd/m²) obtained for each spot at 1.875 m from the floor for the morning measurements, in the Reference room.*

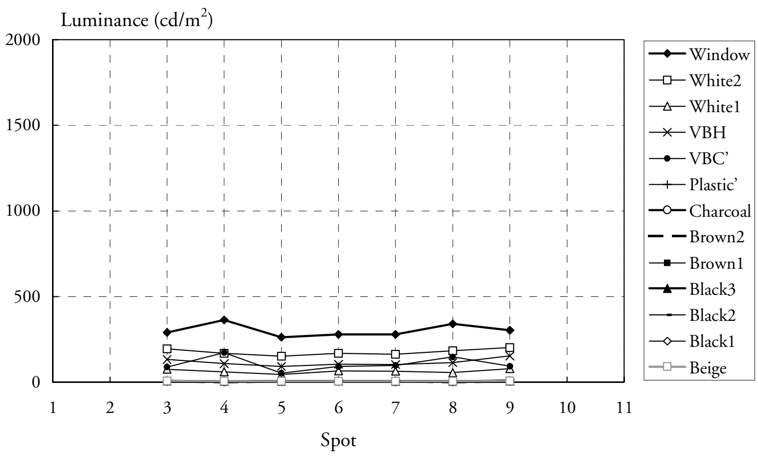



*Figure 3.24* *Luminance values (cd/m²) obtained for each spot at 2.625 m from the floor for the morning measurements, in the Reference room.*

Fig. 3.21 shows that at 0.375 m from the floor, there was a sunlight patch with a luminance over 1000 cd/m$^2$ with the bare window. The problem was prevented by all the shading systems studied. At 1.125 m (Fig. 3.22), the white screens (White1-2) created a bright light patch which was not recorded for the bare window. VBH and VBC also resulted in luminances over 500 cd/m$^2$, while all other shading systems had very low luminance values overall. At 1.875 m (Fig. 3.23), very high luminance values (> 5500 cd/m$^2$) were recorded for the bare window. The white screens (White1-2) and VBH did not reduce the luminance of the sky under 500 cd/m$^2$. White2 and VBH had a luminance close to 3000 cd/m$^2$ and White1 was a bit lower with 1000 cd/m$^2$. All the other points were below 500 cd/m$^2$ except for Black2, which had a luminance slightly above 500 cd/m$^2$ for the spot falling in the window (sky). Note that this value might have been higher if the measurement had been made at another time since the vertical illuminance on the facade was relatively low for this case (see Fig. 3.1). At 2.625 m from the floor (Fig. 3.24), none of the values were above 500 cd/m$^2$.

Similar plots for the noon measurements are presented in Fig. 3.25 to 3.28.

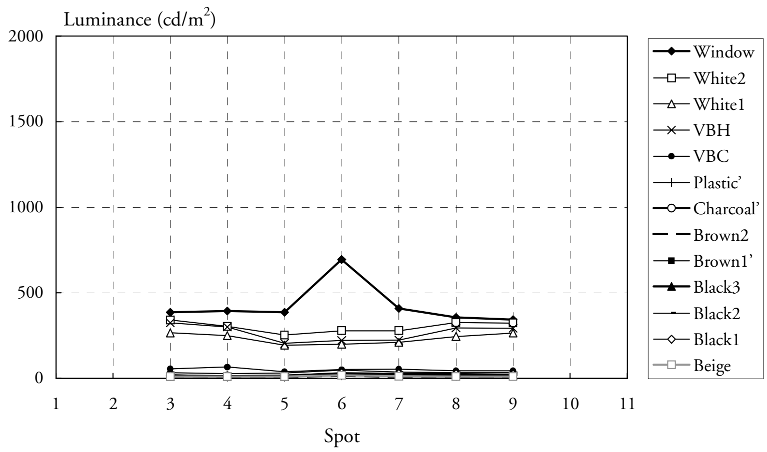



*Figure 3.25 Luminance values (cd/m$^2$) obtained for each spot at 0.375 m from the floor for the noon measurements, in the Reference room.*

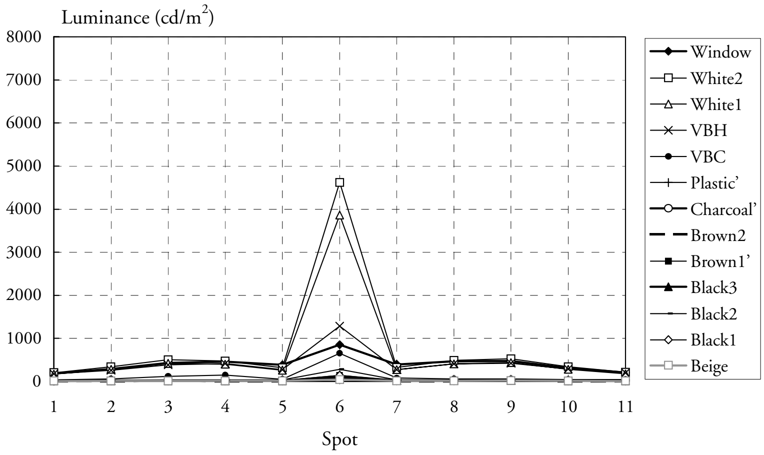



*Figure 3.26* *Luminance values (cd/m$^2$) obtained for each spot at 1.125 m from the floor for the noon measurements, in the Reference room.*

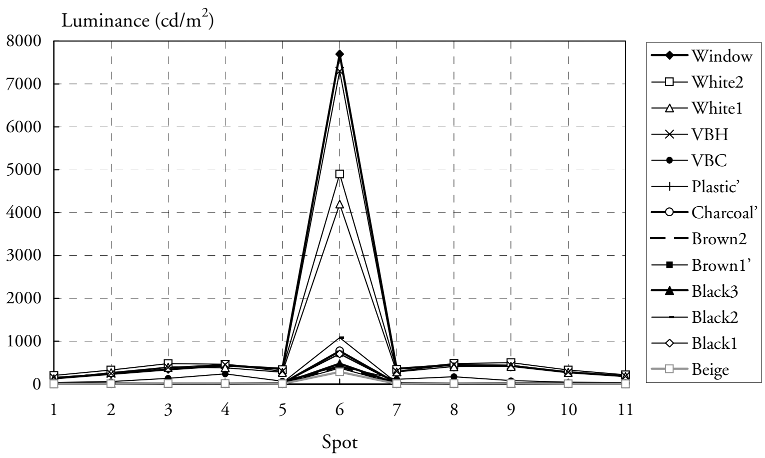



*Figure 3.27* *Luminance values (cd/m$^2$) obtained for each spot at 1.875 m from the floor for the noon measurements, in the Reference room.*

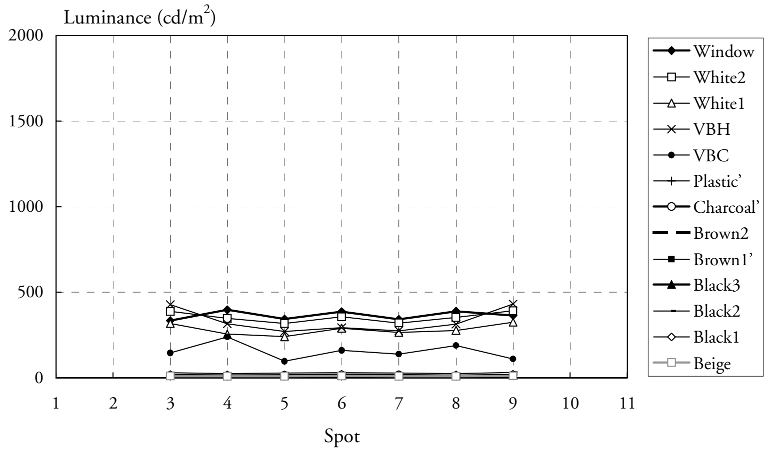



*Figure 3.28 Luminance values (cd/m$^2$) obtained for each spot at 2.625 m from the floor for the noon measurements, in the Reference room.*

Many similarities can be found between these diagrams and the previous diagrams. At 0.375 m from the floor (Fig. 3.25), the same comments made for the morning measurements apply except that the direct sunlight patch (bare window) moved in front of the window creating a bright area with a luminance above 500 cd/m$^2$. At 1.125 m (Fig. 3.26), White1-2 and VBH created a light patch brighter than in the case of the bare window. Even VBC had a luminance value above 500 cd/m$^2$. At 1.875 m (Fig. 3.27), the bare window and VBH had the highest luminance while White1-2 had a point of luminance in the region 4000-5000 cd/m$^2$. Even Black2 had a point of luminance above 1000 cd/m$^2$ and Charcoal, Black1 and VBC all exceeded 500 cd/m$^2$ for the point falling in the window (sky). All the other values were below 500 cd/m$^2$. At 2.625 m (Fig. 3.28), all measured luminance values were below 500 cd/m$^2$.

The plots for the afternoon measurements are presented in Fig. 3.29 to 3.32.

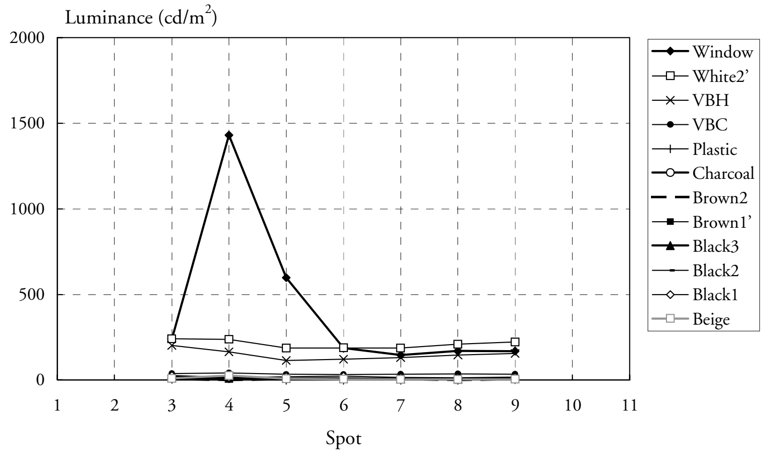



*Figure 3.29* *Luminance values (cd/m²) obtained for each spot at 0.375 m from the floor for the afternoon measurements, in the Reference room.*

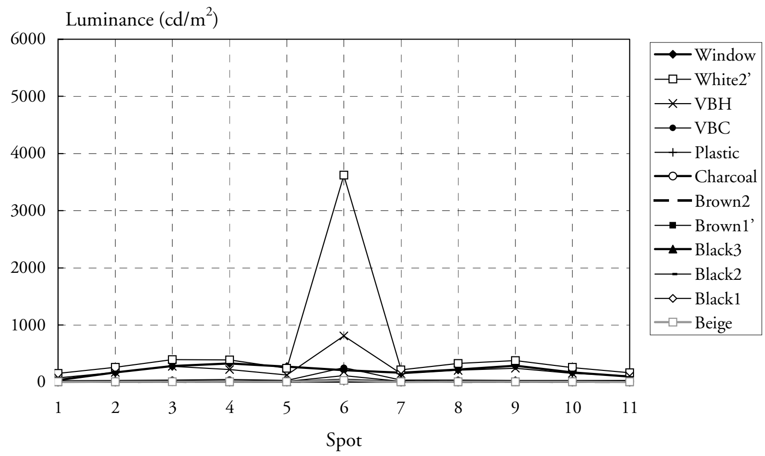



*Figure 3.30* *Luminance values (cd/m²) obtained for each spot at 1.125 m from the floor for the afternoon measurements, in the Reference room.*

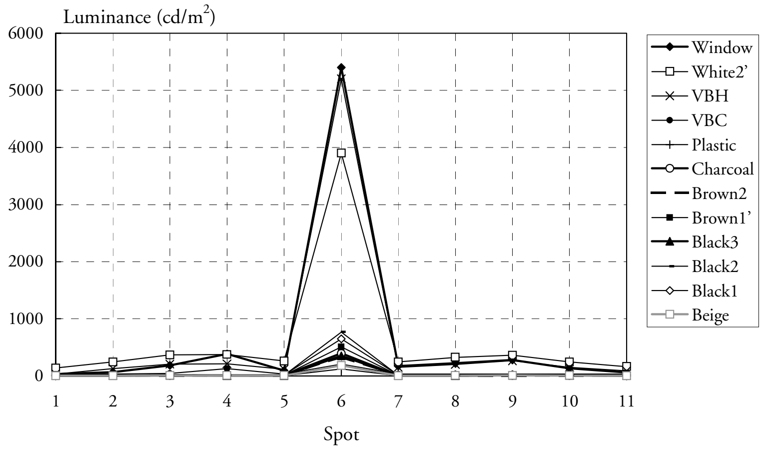



*Figure 3.31 Luminance values (cd/m²) obtained for each spot at 1.875 m from the floor for the afternoon measurements, in the Reference room.*

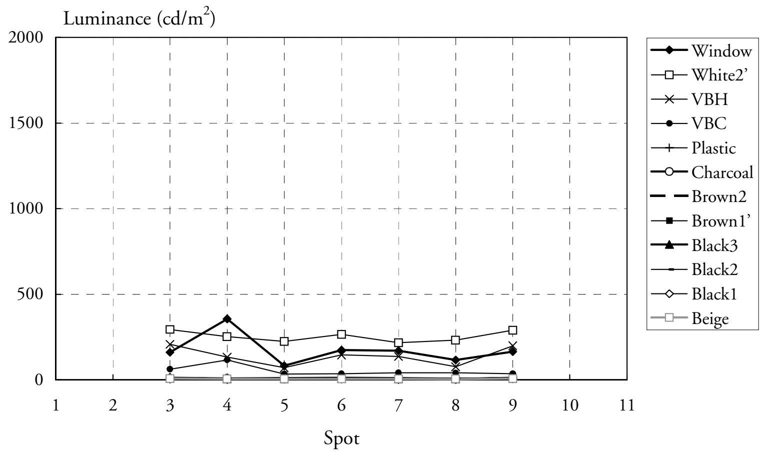



*Figure 3.32 Luminance values (cd/m²) obtained for each spot at 2.625 m from the floor for the afternoon measurements, in the Reference room.*

These figures show that at 0.375 m (Fig. 3.29), there was a bright sunlight patch (around 1500 cd/m$^2$) on the east wall in the case of the bare window. This problem was prevented by all the shading systems tested. At 1.125 m (Fig. 3.30), the same comment as made previously applies but the situation is more dramatic: White2 and VBH create high luminance values (> 3500 cd/m$^2$ for White2 and nearly 1000 cd/m$^2$ for VBH) which did not occur with the bare window. However, a look at Fig. 3.3 reveals that White2 was evaluated when the exterior vertical illuminance on the facade was particularly high. At 1.875 m (Fig. 3.31), the bare window and VBH recorded luminance values above 5000 cd/m$^2$, White2 had 4000 cd/m$^2$ and Black2, Black1 and Brown1 had 500 cd/m$^2$ for the same point. All the other values were below 500 cd/m$^2$. At 2.625 m (Fig. 3.32), all the luminance values recorded were below 500 cd/m$^2$.

Fig. 3.33 to 3.35 show the percentage of points which were above a given luminance for the morning, noon and afternoon measurements, in the Reference room.

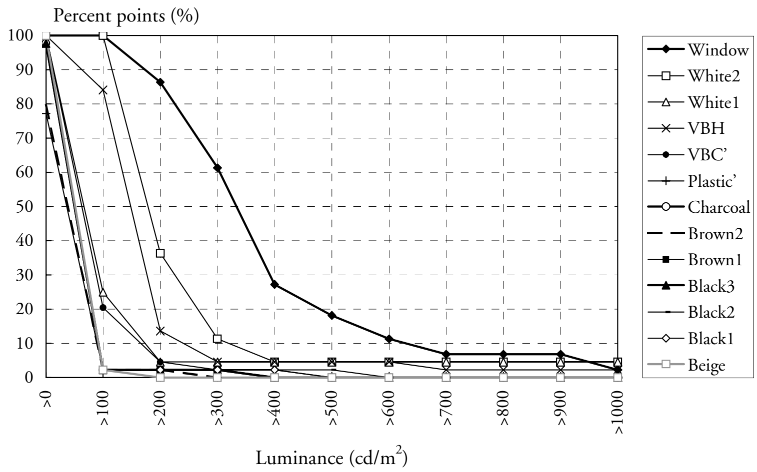



*Figure 3.33* *Percentage (%) of points above a given luminance value for the morning measurements in the Reference room.*

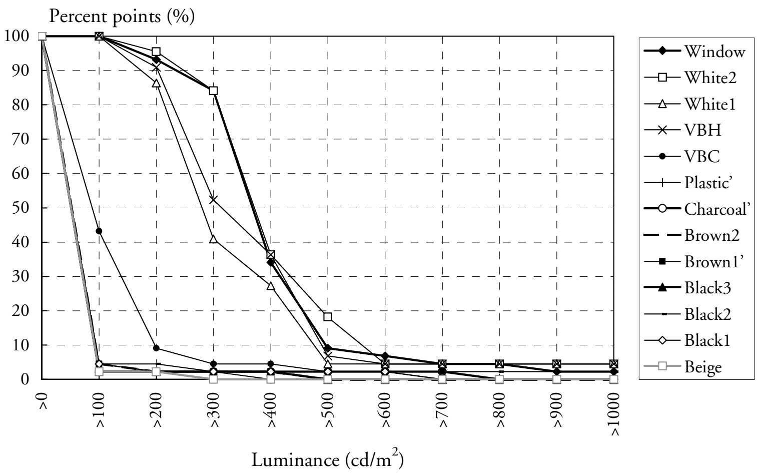



*Figure 3.34* *Percentage (%) of points above a given luminance value for the noon measurements in the Reference room.*

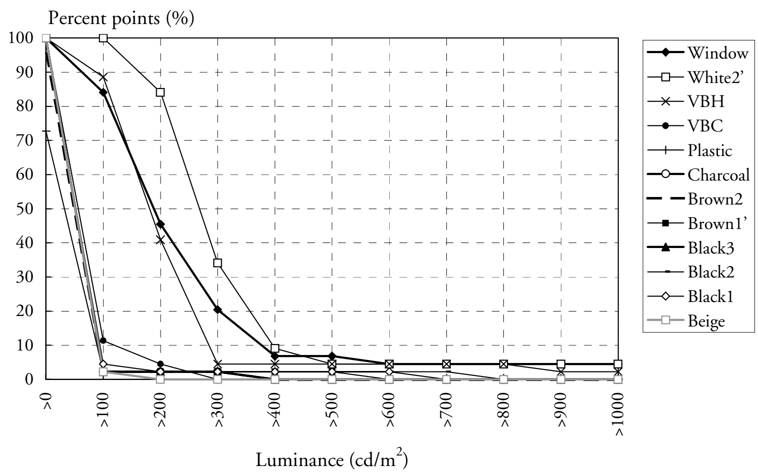



*Figure 3.35* *Percentage (%) of points above a given luminance value for the afternoon measurements in the Reference room.*

Fig. 3.33 shows that, in the morning, a relatively high percentage of points (20 %) had luminances above 500 cd/m$^2$ for the bare window case. The shading systems improved this situation dramatically. The white screens (White1-2) and VBH had around 5 % of the points above 500 cd/m$^2$ but they also had a higher percentage of points (5 %) above 1000 cd/m$^2$. Black2 had some points above 500 cd/m$^2$ as well although the exterior vertical illuminance was relatively low in this case (see Fig. 3.1). Most other shading devices completely prevented luminance values above 500 cd/m$^2$.

At noon time (Fig. 3.34), White2 was worse than the bare window with 20 % of the values above 500 cd/m$^2$ and nearly 5 % above 1000 cd/m$^2$. In comparison, the bare window only had 10 % of the luminance values measured above 500 cd/m$^2$ and around 2-3 % above 1000 cd/m$^2$. VBH and White1 had 5 % of the values above 1000 cd/m$^2$. Other than that, VBC, Black1, Black2, Brown1 and Charcoal all had a small percentage of values above 500 cd/m$^2$. Black2 even had values above 1000 cd/m$^2$. All the other screens completely prevented luminance values above 500 cd/m$^2$.

In the afternoon, Fig. 3.35 shows that the luminance values in the room were higher for White2 than for the bare window case with 100 % of the luminance values studied above 100 cd/m$^2$ and 80 % above 200 cd/m$^2$. However, a look at the exterior illuminance on the facade for the afternoon measurements (Fig. 3.3) indicates that the intensity of the solar radiation on the facade was much higher for White2 than for the bare window. This might explain why Fig. 3.35 shows a higher percentage of high luminance values for the White2 screen compared with the bare window. In fact, if we multiply the luminance values by a factor proportional to the illuminance on the facade, we obtain Fig. 3.36. This figure shows that the curve of White2 is now under that of the bare window with 90 % of the spots above 100 cd/m$^2$, and only around 28 % above 200 cd/m$^2$. Around 5 % of the values are above 1000 cd/m$^2$ as for the bare window. Other than that, the correction factor moderately affects the curve of VBH and negligibly affects the curves of the other shading systems. VBH had 5 % of the values above 500 cd/m$^2$ and around 3 % above 1000 cd/m$^2$ while Black2 had a small percentage of values above 500 cd/m$^2$. All the other shading systems prevented luminance values above 500 cd/m$^2$.

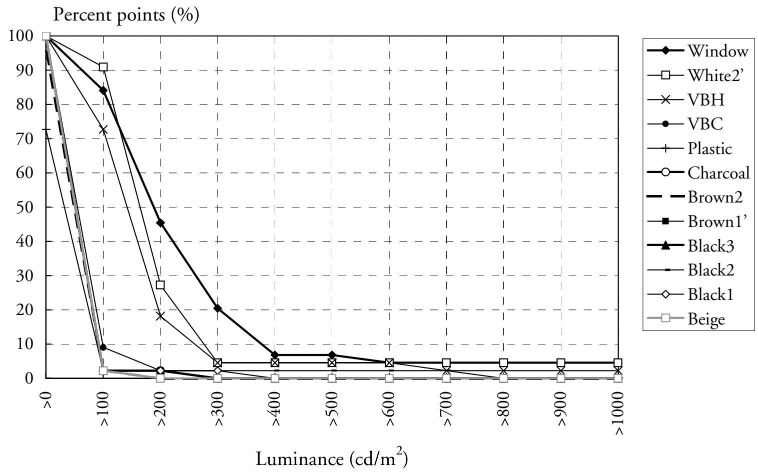



*Figure 3.36* *Percentage (%) of points above a given luminance value for the afternoon measurements in the Reference room. In this figure, the luminance values have been multiplied by a factor proportional to the exterior vertical illuminance on the facade.*

## 3.5.2 Minimum luminance

Although high luminance values are not desirable because of the risk that discomfort or disability glare problems will occur, too low luminances should also be avoided as they make the space appear gloomy and unpleasant. The literature (see Dubois, 2001) suggests that the luminance be maintained above 30 cd/m$^2$ on the walls located directly in the field of view. Fig. 3.37 to 3.39 show the percentage of luminance values which were below a given luminance value for each shading system monitored, for the morning, noon and afternoon measurements in the Reference room. Only the luminance values which fall closest to the central field of view for a sitting person looking straight ahead, i.e. the values located at 1.125 and 1.875 m from the floor, were considered in these figures.

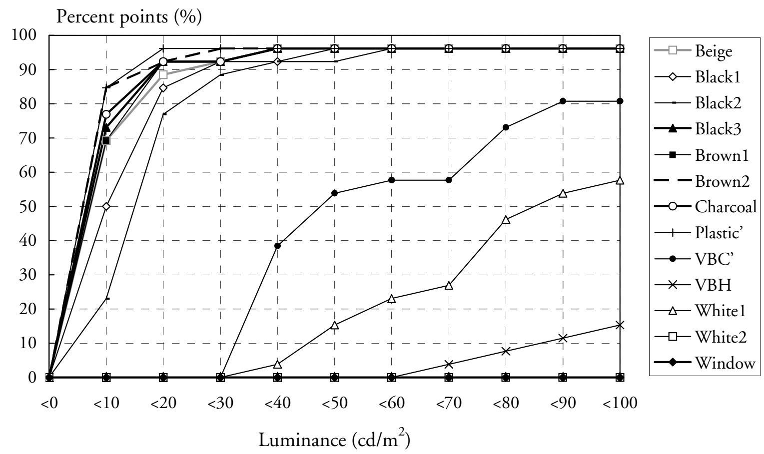



*Figure 3.37* *Percentage (%) of points below a given luminance value for the morning measurements in the Reference room.*

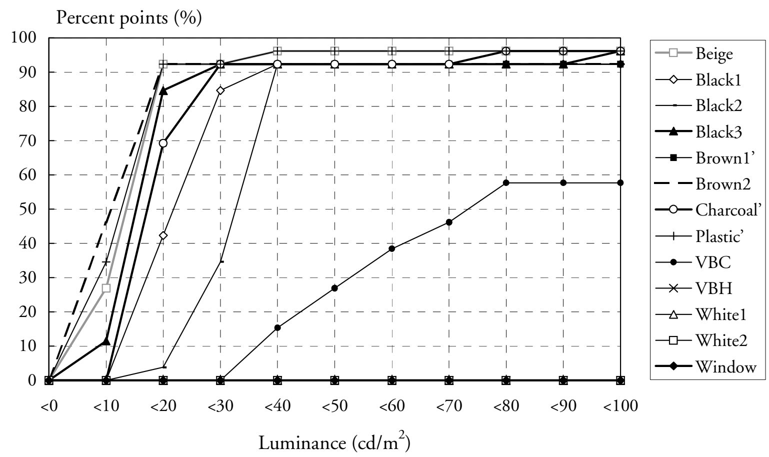



*Figure 3.38* *Percentage (%) of points below a given luminance value for the noon measurements in the Reference room.*

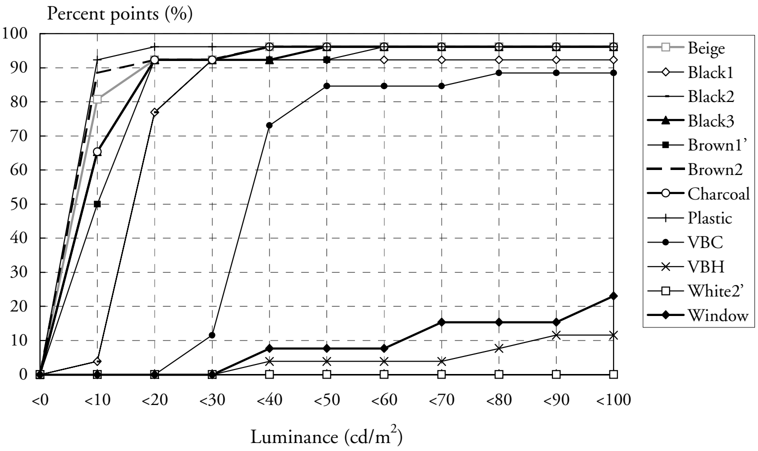



*Figure 3.39* *Percentage (%) of points below a given luminance value for the afternoon measurements in the Reference room.*

Fig. 3.37 shows that, in the morning, most shading systems tested except VBC, White1-2, VBH, and the bare window had the majority (90 %) of their luminance values below 30 cd/m$^2$. Plastic and Brown2 even had 85 % of their luminance values below 10 cd/m$^2$, which is unacceptably low. At noon time (Fig. 3.38), the situation was slightly improved for Black2 with 35 % of the values below 30 cd/m$^2$ but still, 90 % of the values were below 40 cd/m$^2$, which is very low. All the other shading devices had over 90 % of their luminance values below 30 cd/m$^2$. VBC, White1-2, VBH and the bare window had no values below 30 cd/m$^2$. In the afternoon (Fig. 3.39), the comments made for the morning measurements apply as well.

## 3.6 Luminance ratios

The luminance ratios between the work plane or paper task, the adjacent wall (or window) and the VDT screen were also studied.

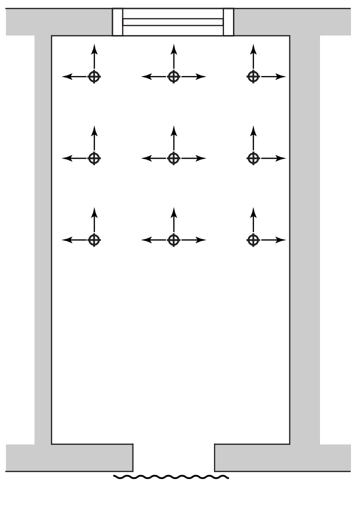
### 3.6.1 Luminance ratios between the paper task and the adjacent wall

This aspect was studied by calculating the ratio between the work plane (paper task) luminance and that of the adjacent wall for 21 possible viewing directions in the Reference room (Fig. 3.40). This analysis includes only the luminance spots on the wall (or window) which were closest to the central field of view of a sitting or a standing person looking straight ahead.

The luminance ($L$) for the work plane was calculated from the work plane illuminance values ($E$) measured using:

$$L = \frac{E \cdot \rho}{\pi} \tag{3.1}$$

Where $E$ is the work plane illuminance and $\rho$ is the reflectance of the surface. We assumed a perfectly diffusing work surface with a reflectance of 80 %, which is approximately the reflectance of a white sheet of paper.



Test room

*Figure 3.40* *21 possible viewing directions which were considered when studying the luminance ratios between the task and the adjacent wall.*

The ratio between each pair of paper task to adjacent wall luminance values was calculated and the number of ratios which exceeded three or were below 0.33 were counted. Most codes require that the luminance ratio between the task and adjacent areas be at most 1:3 or 3:1 (see Table 1.1). Fig. 3.41 to 3.43 show the percentage of ratios which failed to meet the requirement.

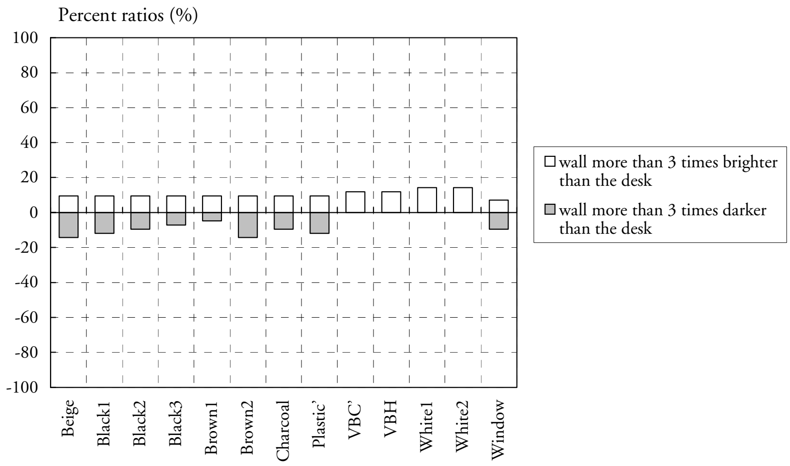



*Figure 3.41* *Percentage (%) of luminance ratios which failed to meet the requirement i.e. the luminance ratio between the paper task and the adjacent wall exceeded 1:3 or 3:1, morning measurements, Reference room.*

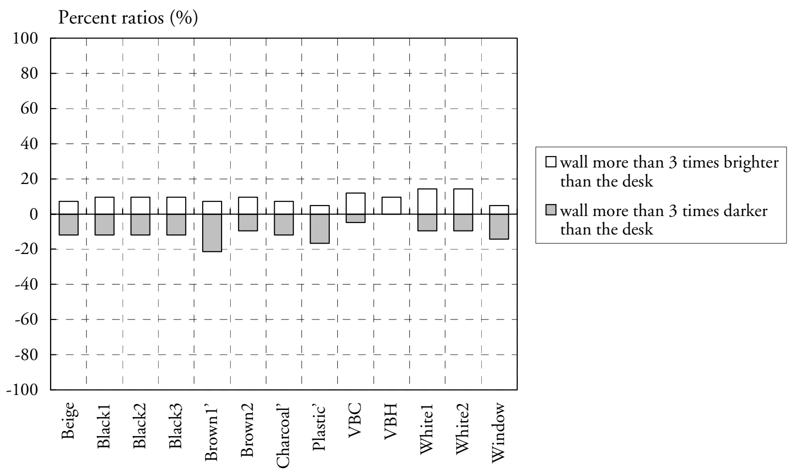



*Figure 3.42* *Percentage (%) of luminance ratios which failed to meet the requirement i.e. the luminance ratio between the paper task and the adjacent wall exceeded 1:3 or 3:1, noon measurements, Reference room.*

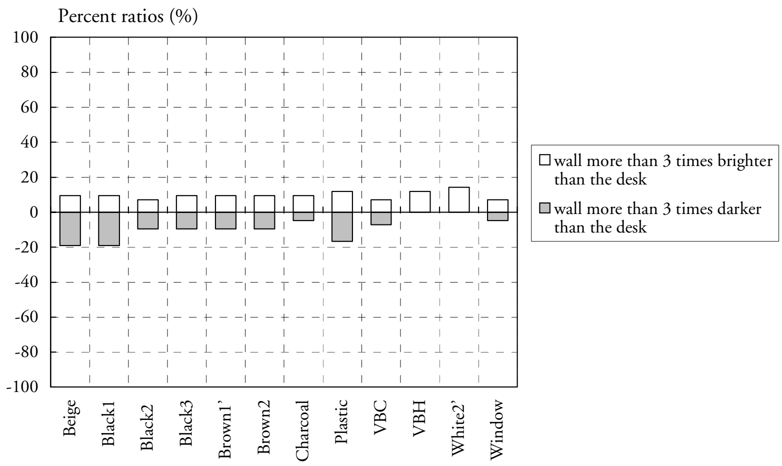



*Figure 3.43* *Percentage (%) of luminance ratios which failed to meet the requirement i.e. the luminance ratio between the paper task and the adjacent wall exceeded 1:3 or 3:1, afternoon measurements, Reference room.*

Fig. 3.41 to 3.43 show that the luminance ratio between the task and the adjacent wall did meet the requirement for the majority of the cases. In the worst case (Brown1', noon), only 21 % of the ratios studied did not meet the requirement. In general, dark shading fabrics (Beige, Black1-2-3, Brown1-2, Charcoal, Plastic) resulted in a larger number of ratios for which the wall was more than three times darker than the paper task. The contrary, i.e. the wall three times brighter than the task, was observed for VBC, VBH, White1-2. VBH generally performed slightly better than the other devices tested.

### 3.6.2 Luminance ratios between the VDT screen and the adjacent wall

The luminance ratio between a VDT screen and the wall directly behind was also studied for the 21 viewing directions shown in Fig. 3.40.

The luminance of the VDT screen is a fairly constant value. The average luminance of a standard computer screen is around 90 cd/m$^2$ but can vary between around 5 cd/m$^2$ for a black background to 120 cd/m$^2$ for a white background with the highest brightness level. In this case, we assumed only white backgrounds and thus assumed that the luminance of the screen varied between 60-120 cd/m$^2$. These values are based on measurements carried out on ordinary VDT screens at the Dept. of Construction and Architecture at Lund University, Sweden.

The ratio between a 60-120 cd/m$^2$-VDT screen and the luminance of the wall behind the screen was studied for the 21 viewing directions shown in Fig. 3.40. Fig. 3.44 to 3.46 show the percentage of ratios which failed to meet the requirement expressed in Table 1.1 i.e. the screen was more than three times brighter or three times darker than the adjacent wall.

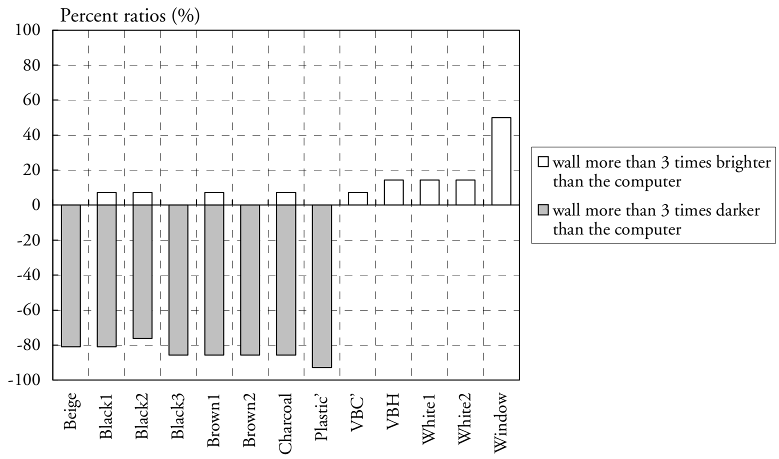



*Figure 3.44* *Percentage (%) of luminance ratios which failed to meet the requirement i.e. the luminance ratio between the VDT screen and the adjacent wall exceeded 1:3 or 3:1, morning measurements, Reference room.*

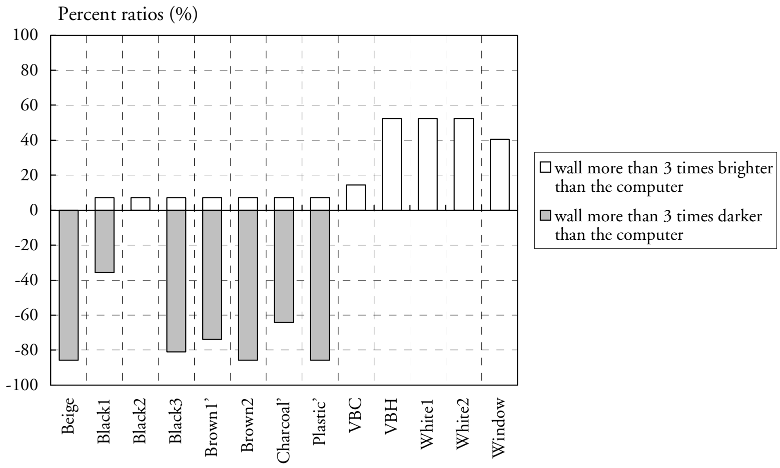



*Figure 3.45* *Percentage (%) of luminance ratios which failed to meet the requirement i.e. the luminance ratio between the VDT screen and the adjacent wall exceeded 1:3 or 3:1, noon measurements, Reference room.*

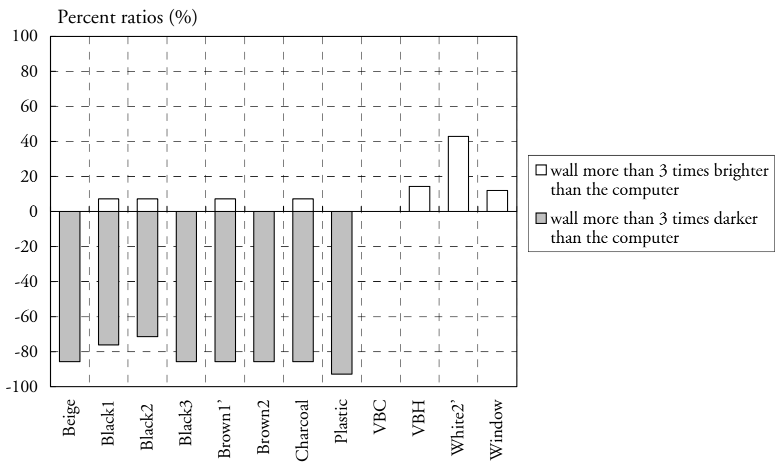



*Figure 3.46* *Percentage (%) of luminance ratios which failed to meet the requirement i.e. the luminance ratio between the VDT screen and the adjacent wall exceeded 1:3 or 3:1, afternoon measurements, Reference room.*

Fig. 3.44 to 3.46 clearly show that for dark screens (Beige, Black1-3, Brown1-2, Charcoal and Plastic), the wall was more than three times darker than the VDT screen for the majority of the ratios studied. The only exception was Black1-2 at noon time where only a minority of ratios failed to meet the requirement. For VBC, VBH, White1-2 and the bare window, the opposite problem occurred i.e. the wall was often more than three times brighter than the VDT screen. But this problem occurred for at most 50 % of the ratios studied. VBC performed better than the other shading devices at all times with at most 15 % of the ratios not meeting the requirement at noon time.

### 3.6.3 Luminance ratios between the paper task and the VDT screen

Finally, the luminance ratio between the paper task and the computer screen was studied. The same assumption regarding the task was made i.e. the task consisted of a white diffusing sheet of paper with a reflectance of 80 %. The luminance values for the task were thus calculated from the illuminance values measured at nine points in the Reference room. Fig. 3.47 to 3.49 show the percentage of ratios studied which failed to meet the requirement i.e. the VDT screen was more than three times brighter or three times darker than the paper task.

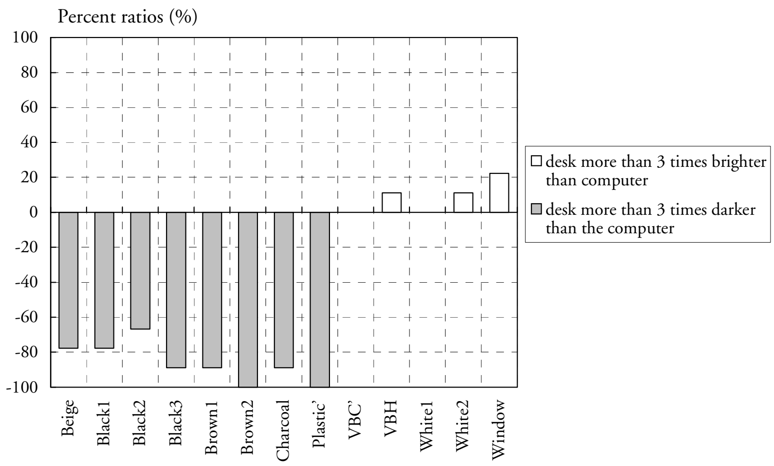



*Figure 3.47* *Percentage (%) of luminance ratios which failed to meet the requirement i.e. the luminance ratio between the paper task and the VDT screen exceeded 1:3 or 3:1, morning measurements, Reference room.*

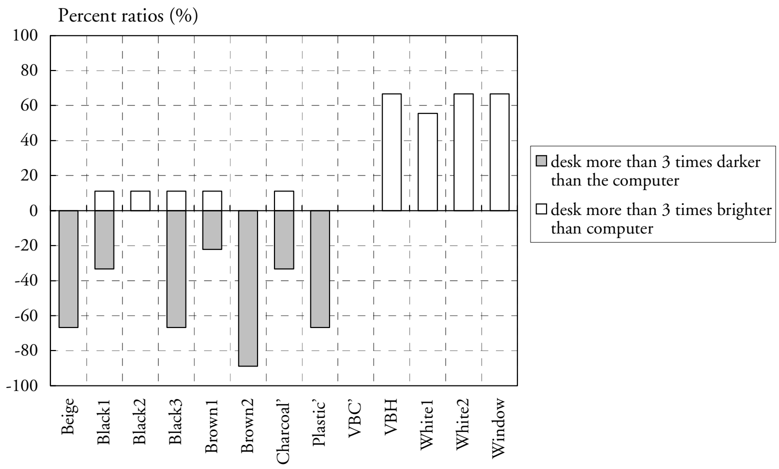



*Figure 3.48* *Percentage (%) of luminance ratios which failed to meet the requirement i.e. the luminance ratio between the paper task and the VDT screen exceeded 1:3 or 3:1, noon measurements, Reference room.*

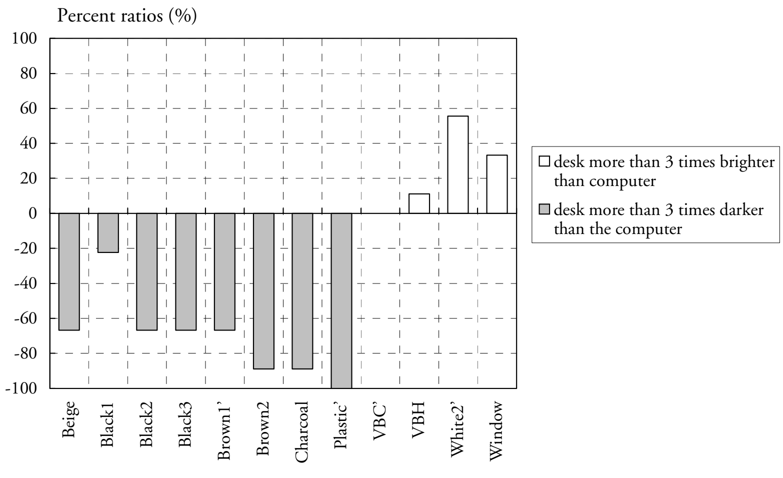



*Figure 3.49* *Percentage (%) of luminance ratios that failed to meet the requirement i.e. the luminance ratio between the paper task and the VDT screen exceeded 1:3 or 3:1, afternoon measurements, Reference room.*

Fig. 3.47 to 3.49 show the same trend as for the luminance ratios between the VDT screen and the adjacent wall, i.e. dark-coloured screens resulted in the majority of the luminance ratios for which the task was more than three times brighter than the VDT screen. Likewise, the light-coloured screens (White1-2), VBC, VBH and the bare window yielded the opposite problem i.e. the task was more than three times brighter than the computer screen. Again, VBC and VBH performed better than the other devices, especially in the afternoon.

### 3.6.4 Luminance ratios between the window (sky) and the walls

One aspect which also deserves consideration is the luminance ratio between the window (sky part) and the rest of the room. The experimenter noticed during the measurements that the brightness of the window was often very uncomfortable for the eye because the contrast between the window and the rest of the room was fairly high. This aspect was thus also studied. The codes (e.g. NUTEK, 1994) recommend that the luminance ratio should not exceed 1:20 between any part of the room. Table 3.2 summarises the average values obtained for the central part of the wall (horizontal band) compared with the value measured in the middle of the window (sky). The luminance ratio between the two values is also shown in Table 3.2 and illustrated in Fig. 3.50.

Table 3.2 Average wall luminance (cd/m$^2$), for the central band closest to the central field of view, luminance (cd/m$^2$) of the window (sky part) and luminance ratio between the two values for the morning, noon and afternoon measurements in the Reference room.

| | Luminance window (sky) (cd/m$^2$) | | | Average luminance walls (cd/m$^2$) | | | Luminance ratio window-walls | | |
|---|---|---|---|---|---|---|---|---|---|
| System | Morning | Noon | Afternoon | Morning | Noon | Afternoon | Morning | Noon | Afternoon |
| Beige | 199 | 286 | 183 | 9 | 11 | 8 | 23 | 27 | 24 |
| Black1 | 433 | 700 | 649 | 10 | 20 | 17 | 42 | 35 | 38 |
| Black2 | 555 | 1079 | 770 | 14 | 29 | 16 | 41 | 37 | 47 |
| Black3 | 316 | 478 | 354 | 8 | 14 | 9 | 40 | 34 | 39 |
| Brown1 | 367 | 707 | 508 | 9 | 17 | 11 | 42 | 43 | 47 |
| Brown2 | 282 | 425 | 334 | 5 | 10 | 7 | 53 | 44 | 49 |
| Charcoal | 390 | 774 | 396 | 8 | 17 | 10 | 51 | 47 | 41 |
| Plastic | 164 | 377 | 119 | 4 | 11 | 5 | 39 | 36 | 25 |
| VBC | 265 | 414 | 204 | 57 | 82 | 42 | 5 | 5 | 5 |
| VBH | 2977 | 7300 | 5200 | 142 | 313 | 205 | 21 | 23 | 25 |
| White1 | 1162 | 4200 | missing | 78 | 305 | missing | 15 | 14 | missing |
| White2 | 2754 | 4900 | 3900 | 195 | 368 | 328 | 14 | 13 | 12 |
| Window | 5800 | 7700 | 5400 | 319 | 339 | 227 | 18 | 23 | 24 |

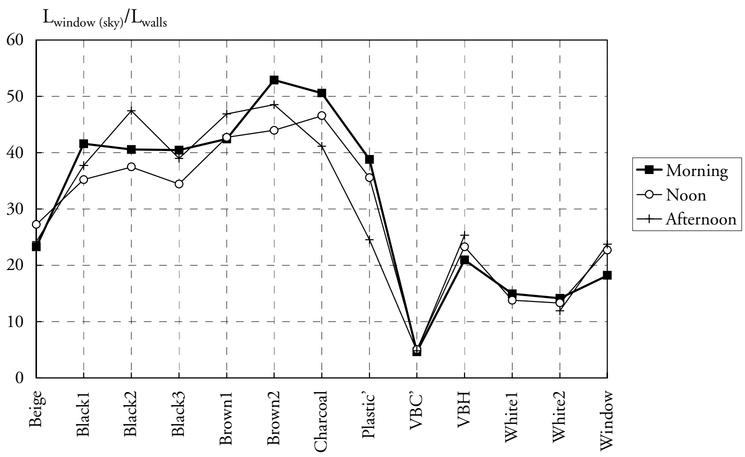



*Figure 3.50* *Luminance ratio between the window ($L_{window\ (sky)}$) and average wall luminance ($L_{walls}$).*

Fig. 3.50 shows that the dark-coloured screens (Beige, Black1-3, Brown1-2, Charcoal, Plastic) resulted in much higher luminance ratios (all over 20) than the light-coloured screens (White1-2). The worst screens were Brown2 and Charcoal. These screens reduced the daylight in the room to such a point that the contrast (ratio) between the window and the rest of the room was over 40. The light-coloured screens performed better and had lower luminance ratios but the best performing shading device was VBC, which reduced the luminance from the window dramatically while leaving enough diffuse light through the slats so that the room remained relatively bright compared with the luminance of the window.

### 3.6.5 Luminance ratios between the sunlight patches and the walls

Another source of nuisance was the bright patch of direct sunlight which sometimes penetrated into the room. The ratio between these direct sunlight patches and the average wall luminance was thus also studied. Table 3.3 shows the luminance values measured for the sunlight patch compared with the average luminance value of the walls (central band) and the resulting luminance ratio between the two values.

Table 3.3 Average wall luminance (cd/m$^2$), for the central band closest to the central field of view, luminance (cd/m$^2$) of the direct sunlight patch and luminance ratio between the two values for the morning, noon and afternoon measurements in the Reference room.

| | Luminance, sunlight patch (cd/m$^2$) | | | Luminance, walls (cd/m$^2$) | | | Luminance ratio sunlight patch-walls | | |
|---|---|---|---|---|---|---|---|---|---|
| System | Morning | Noon | Afternoon | Morning | Noon | Afternoon | Morning | Noon | Afternoon |
| Beige | 120 | 70 | 20 | 9 | 11 | 8 | 14 | 7 | 3 |
| Black1 | 25 | 165 | 45 | 10 | 20 | 17 | 2 | 8 | 3 |
| Black2 | none | 250 | none | 14 | 29 | 16 | - | 9 | - |
| Black3 | none | 110 | 17 | 8 | 14 | 9 | - | 8 | 2 |
| Brown1 | none | 69 | none | 9 | 17 | 11 | - | 4 | - |
| Brown2 | none | 60 | none | 5 | 10 | 7 | - | 6 | - |
| Charcoal | none | 105 | none | 8 | 17 | 10 | - | 6 | - |
| Plastic | none | 65 | none | 4 | 11 | 5 | - | 6 | - |
| VBC | none | none | none | 57 | 82 | 42 | - | - | - |
| VBH | none | none | none | 142 | 313 | 205 | - | - | - |
| White1 | none | 210 | missing | 78 | 305 | missing | - | 1 | missing |
| White2 | none | 200 | none | 195 | 368 | 328 | - | 1 | - |
| Window | 7500 | 3000 | 5400 | 319 | 339 | 227 | 24 | 9 | 24 |

Table 3.3 shows that direct sunlight patches can have a very high luminous intensity. For example, the bare window created a sunlight patch of 7500 cd/m$^2$ in the morning and 5400 cd/m$^2$ at noon time. In the morning, the luminance of the sunlight patch was higher than the luminance of the sky and was 24 times brighter than the average luminance of the walls. Table 3.3 also shows that Black1 and Beige always created sunlight patches, morning, noon and afternoon, while the other shading devices often prevented this problem in the morning and afternoon. None of the shading devices tested except VBC and VBH prevented sunlight patches at noon time although all the shading devices significantly reduced the luminous intensity of the sunlight patch as shown in Table 3.3.

## 3.7 Overall performance

Table 3.4 shows the average values obtained for the morning, noon and afternoon measurements for each performance indicator considered in the Reference room.

Table 3.4 Average of morning, noon and afternoon measurements for all the performance indicators considered, Reference room.

| | | | Group | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | | | | | | | | 2 | 3 | | | |
| | | System | Beige | Black1 | Black2 | Black3 | Brown1 | Brown2 | Charcoal | Plastic | VBC | VBH | White1 | White2 | Window |
| DAYLIGHT FACTOR | | Average A1-A4 (%) | 0.26 | – | 0.78 | 0.37 | 0.34 | – | – | 0.24 | – | – | 1.68 | 1.98 | – |
| | | Average A1-A10 (%) | 0.17 | – | 0.50 | 0.23 | 0.20 | – | – | 0.15 | – | – | 1.28 | 1.50 | – |
| | | Middle point (%) | 0.09 | – | 0.21 | 0.10 | 0.10 | – | – | 0.08 | – | – | 0.69 | 0.82 | – |
| WORK PLANE ILLUMINANCE | Percent points (%) below or above a given value | < 100 lx | 87 | 60 | 47 | 83 | 70 | 93 | 80 | 90 | 0 | 0 | 0 | 0 | 0 |
| | | < 300 lx | 97 | 90 | 97 | 97 | 93 | 97 | 97 | 97 | 33 | 0 | 20 | 0 | 0 |
| | | < 500 lx | 97 | 90 | 97 | 97 | 97 | 97 | 97 | 97 | 83 | 13 | 35 | 0 | 0 |
| | | > 500 lx | 3 | 10 | 3 | 3 | 3 | 3 | 3 | 3 | 17 | 87 | 65 | 100 | 100 |
| | | Average illuminance (lx) | 99 | 246 | 278 | 134 | 139 | 70 | 131 | 76 | 362 | 1160 | 1043 | 1478 | 4216 |
| ILLUMINANCE UNIFORMITY | Percent ratios (%) not meeting the requirement | Emin/Emax > 0.5 | 30 | 35 | 24 | 30 | 41 | 28 | 26 | 28 | 0 | 20 | 25 | 24 | 28 |
| | | Emin/Emax > 0.7 | 63 | 61 | 56 | 57 | 61 | 56 | 56 | 65 | 35 | 57 | 58 | 56 | 56 |
| | | Emin/Eav > 0.8 | 57 | 56 | 52 | 54 | 57 | 50 | 52 | 57 | 35 | 50 | 53 | 56 | 52 |
| ABSOLUTE LUMINANCE | Percent points (%) below or above a given value | < 30 cd/m$^2$ | 92 | 90 | 72 | 92 | 92 | 94 | 92 | 95 | 4 | 0 | 0 | 0 | 0 |
| | | > 500 cd/m$^2$ | 0 | 2 | 2 | 0 | 2 | 0 | 1 | 0 | 1 | 5 | 5 | 9 | 11 |
| | | > 1000 cd/m$^2$ | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 5 | 5 | 3 |
| | | Maximum luminance (cd/m$^2$) | 223 | 594 | 801 | 383 | 527 | 347 | 520 | 220 | 439 | 5159 | 3087 | 4351 | 4977 |
| LUMINANCE RATIOS | Percent ratios (%) not meeting the requirement | Wall more than 3 times brighter than task | 9 | 10 | 9 | 10 | 9 | 10 | 9 | 9 | 10 | 11 | 14 | 14 | 6 |
| | | Wall more than 3 times darker than task | 15 | 14 | 10 | 10 | 12 | 11 | 9 | 15 | 4 | 0 | 5 | 3 | 10 |
| | | Wall more than 3 times brighter than VDT | 0 | 7 | 7 | 2 | 7 | 2 | 7 | 2 | 7 | 27 | 33 | 37 | 34 |
| | | Wall more than 3 times darker than VDT | 84 | 64 | 49 | 84 | 82 | 86 | 79 | 90 | 0 | 0 | 0 | 0 | 0 |
| | | Task more than 3 times brighter than VDT | 0 | 4 | 4 | 4 | 4 | 0 | 4 | 0 | 0 | 30 | 28 | 44 | 41 |
| | | Task more than 3 times darker than VDT | 70 | 44 | 44 | 74 | 59 | 93 | 70 | 89 | 0 | 0 | 0 | 0 | 0 |
| | Average ratios | Window (sky) - walls | 25 | 38 | 42 | 38 | 44 | 48 | 46 | 33 | 5 | 23 | 14 | 13 | 22 |
| | | Sunlight patch - walls | 8 | 4 | - | - | - | - | - | - | - | - | - | - | 19 |

Table 3.4 shows that the shading systems studied can more or less be divided into three distinct groups as indicated in the table.

## Regarding the daylight factor

The results show that the systems of Group 1 result in daylight factors below 1 %, which means that artificial lighting will be necessary almost at all times. The screen Black2 had the highest value among this group while the shading systems of Group 3 that have been monitored had average daylight factors above 1 % meaning that there will be acceptable levels of lighting (i.e. over 100 lx) during most overcast days. However, extra artificial lighting will be needed to reach the 500 lx necessary for traditional paper tasks.

## Regarding the work plane illuminance

The results show that the shading systems of Group 1 had the majority of their illuminance values below 100 lx, which is too low according to most codes and will require extra artificial lighting. Among this group, the screen Black2 provided the highest illuminance values and might be acceptable, especially for computer work but is definitely too dark for paper work. However, Fig. 3.1 and 3.3 show that this system was monitored when the exterior vertical illuminance was relatively low, which suggests that this screen's performance might be slightly better than that shown in Table 3.4. The shading devices of Group 3 had a majority of illuminance values above 500 lx, which may make them unsuitable for computer work. The closed venetian blind (VBC, Group 2) had a large portion of illuminance values between 300 and 500 lx, which makes it suitable for both computer and paper work. The illuminance values of screen White1 (Group 3) also indicate that this system might be acceptable for offices where both paper and computer work is carried out.

## Regarding the illuminance uniformity on the work plane

The results show that the difference between the shading systems is not as clear as for the previous performance indicators. Table 3.4 shows that when the least severe requirement ($E_{min}/E_{max} > 0.5$) is applied, most of the systems tested met the requirement. However, when more severe requirements are applied ($E_{min}/E_{max} > 0.7$ or $E_{min}/E_{av} > 0.8$), most systems did not meet the requirements for the majority of the ratios studied. The only exception to this was VBC (Group 2), which met all the requirements for the majority of the ratios studied. Otherwise, the difference between the other shading systems is not significant.

## Regarding the absolute luminance

The results clearly show the distinction between the three groups. The shading devices of Group 1 result in a high percentage of the spots studied with values below 30 cd/m$^2$, which is regarded as too low according to research in the field. On the other hand, these shading systems do prevent high luminance values that occur with the shading systems of Group 3. The shading devices of Group 3 do not create problems with low luminances but they do generate too high luminance values at the window. The exception here is VBC (Group 2), which had a negligible percentage of spots below 30 cd/m$^2$, as well as a negligible percentage of spots above 500 cd/m$^2$. The white screens (Group 3) are especially susceptible to yield high luminance values, but White1 was better than White2. However, note that White1 also had a relatively low exterior vertical illuminance in the morning and that no afternoon measurements were included in the analysis.

## Regarding the luminance ratios

The results show that the luminance ratios between the paper task and the wall were acceptable for the majority of the systems and viewing directions studied. There was a slight tendency for the shading devices of Group 1 to have the wall more than three times darker than the task while the opposite was observed for the shading devices of Group 3. Regarding the luminance ratios between the walls and the VDT screen and between the paper task and VDT screen, the systems of Group 1 resulted in unacceptable luminance ratios, with the walls and task more than three times darker than the VDT while the opposite was observed for the shading systems of Group 3, although the problem was not as important. Once again, an exception to this was VBC (Group 2), which resulted in acceptable luminance ratios between the paper task, the VDT screen and the walls. Also among Group 1, Black1-2 performed slightly better than the other shading systems in that group.

One problem with the shading systems of Group 1 was that the ratio between the window (sky) and the walls was much too high (above 20 in all the cases). The shading devices of Group 3 tended to perform better in this regard and VBC (Group 2) was the best with an average ratio of five, which is acceptable. The table also shows that most shading systems tested in this study, except Black1 and Beige, did prevent bright direct sunlight patches in the room except at noon time. In the case of the bare window, the ratio between the sunlight patch and the walls was on average 19, which is unacceptable if the sunlight patch falls in the normal field of view.

# 4 Discussion and conclusions

The impact of various shading devices on five daylighting quality performance indicators was studied in standard office rooms. The study was entirely carried out through measurements of illuminance and luminance in the rooms, using lux and luminance meters as well as a calibrated, scientific grade CCD camera. The measurements were performed in the Daylight Laboratory of the Danish Building and Urban Research Institute in Hørsholm, Denmark.

The results of the measurements show that the shading systems studied can be divided into three distinct groups:

**Group 1:**

- Beige
- Black1
- Black2
- Black3
- Brown1
- Brown2
- Charcoal
- Plastic

**Group 2:**

- VBC

**Group 3:**

- VBH
- White1
- White2
- (Window)

The shading systems of Group 1 resulted in work plane illuminances which were unacceptably low. The majority of the measured points had an illuminance below 100 lx (under clear sky of 65-95 klx global illuminance). Likewise, the daylight factor of these systems was well below 1 %, which means that extra artificial lighting will be required on overcast days. The results from sunny day measurements also indicate that artificial lighting may even be required under sunny conditions since the illuminance was below 100 lx for most points in the room. The experiment showed that these dark screens do, however, reduce the absolute luminance of the window compared with the bare window case. However, in most cases the luminance of the inner walls was too low, which made the room appear gloomy. These low light levels also resulted in unacceptable luminance ratios between the paper task and the VDT screen and between the VDT screen and the wall behind. Finally, another problem was that the contrast between the window and the rest of the room was much too high. The experimenter noticed a high level of discomfort glare when looking directly at the window.

The differences between the screens of Group 1 were marginal and could as well be attributed to the differences in sky conditions. The only screen among this group which performed significantly better than the others was the screen Black2, which had a slightly higher light transmittance (around 13 %). However, this screen did result in higher luminance values at the window.

The shading systems of Group 3 had acceptable workplane illuminance levels, which were often above 500 lx on sunny days (under clear sky of 57-93 klx global illuminance). The daylight factor was even above 1 % near the window, which is acceptable but will nevertheless require extra artificial lighting under overcast conditions. All the shading devices of this group generally had a light level on the task that was suitable for traditional paper tasks but which may be too high for working on a computer. The major problem with the shading devices of Group 3 was that they resulted in high luminance values at the window. The screens White1-2 became like a bright veil of light under direct sunlight, which had the effect that a large portion of the window had luminance values above 3000 cd/m$^2$. The shading devices of Group 3 also created some unsuitable luminance ratios between the paper task and the VDT screen and between the paper task and the adjacent wall. The walls and task were in general too bright compared with the VDT for around 30 % of the ratios studied.

The closed venetian blind (VBC, Group 2) had ideal illuminance levels for combining traditional paper tasks and computer work and limited luminance to just below 500 cd/m$^2$. Moreover, this system generally prevented extreme (high and low) luminance values. VBC also performed best in terms of luminance ratios between the paper task, the walls and VDT screen.

The study thus shows that only one shading device (VBC) performed well according to all the performance indicators considered. Among the other shading devices, the dark-coloured screens reduced the high luminance values from the sky significantly but they created unacceptably gloomy interiors with low illuminance and luminance values. On the other hand, the light-coloured screens did provide sufficient lighting levels, both in terms of horizontal work plane illuminance and vertical luminance, but they did not successfully prevent bright luminance from the sky. The white screens even exacerbated the problem because they distributed the sky luminance over the whole surface of the screen and created a bright luminous veil covering the whole window area. Only one shading device (VBC) provided adequate illuminance on the work plane and on the walls and prevented the high sky luminance values. However, the view through the window was totally blocked in this case, an aspect which may be unfavourably regarded by the users.

In general, the dark-coloured screens provided a beautiful view through the window. The view was particularly nice with the black (Black1-2-3) and brown (Brown1-2, Charcoal, and Beige) screens. The white screens did not provide a view out under the direct sun since they became like a bright veil of light which reduced the contrast in the scene viewed through the window. The screen Plastic provided a bizarre view because the pattern of this screen was very irregular, which made the outside view look like a "noisy" image.

A study of the difference between the Reference (empty) and Test (furnished) room revealed that both the illuminance and luminance values were by about 26 % on average lower in the Test room than in the Reference room. This means that the performance of the shading devices of Group 1 (and 2) will be poorer in a furnished room since the illuminance and luminance values will be even lower while the luminance of the window will be unchanged. Thus, the contrast between the window and the rest of the room will even be higher than in the case of an empty room. On the other hand, the shading devices of Group 3 will perform slightly better in a furnished room than in an empty room since the illuminance and luminance levels will be lower, which will provide lighting levels that are more compatible with computer work.

In this study, only extremely light- and dark-coloured shading devices were studied. Moreover, the shading devices had either low or high light transmittance values. The results obtained for the screen Black2, which had a slightly higher light transmittance, suggest that screens with intermediate light transmittance may yield more acceptable work plane illuminance and wall luminance values. The study thus suggests that screens with medium colours and intermediate light transmittance values should be investigated as well.

This study suggests that dark-coloured screens, which provide a view through the window, should be used in offices where most of the tasks are computer-based and especially in offices where the user is directly facing the window. In this case, only the dark screens reduce the sky luminance to acceptable levels. However, artificial lighting on the walls and task should be provided in this case and it should also be possible to pull the shading screens up when the outdoor illuminance levels are low. This study also suggests that in offices where a combination of paper and computer tasks are carried out, a conventional light-coloured venetian blind may be a better solution on the south facade than light-coloured screens, which create a bright luminous veil over the whole window area and light levels that may be too high for computer work. Finally, the study shows that the use of white screens on south facades is doubtful since the white screen exacerbates the glare from the window and blocks the view out. Additional measurements need to be carried out to see whether these screens can be used in other orientations.

In this study, the daylight quality was assessed using performance indicators which have mostly been developed for artificial lighting installations. However, it has been shown that people tend to have a much higher tolerance with daylighting than with artificial lighting (see e.g. Chauvel et al., 1982). This means that the evaluation criteria used in this report may be a little severe. It is possible, for example, that people would accept luminance values at the window above 500 cd/m$^2$. In that case, the screen Black2 may be an acceptable solution for a south-oriented office room. Studies with research subjects should be carried out on these types of screens to supplement the results of the present research.

# Summary

The impact of shading devices on the daylight quality in offices was studied through measurements in two south-oriented, experimental rooms located in the Daylight Laboratory of the Danish Building and Urban Research Institute, Hørsholm, Denmark. The daylighting quality was assessed by considering five performance indicators: the daylight factor, the work plane illuminance, the illuminance uniformity on the work plane, the absolute luminance in the field of view and the luminance ratios between the work plane (paper task), the walls and the VDT screen. These performance indicators were determined after a literature review, which is reported in Dubois (2001).

The shading systems studied included ten interior shading (roller) screens and one standard venetian blind with 25 mm-wide, curved, white aluminium slats placed on the interior side of the window. Among the interior screens studied, three were black, one was dark brown, two were brown, two were medium brown and two were white. The venetian blind was studied with the slats in the horizontal position and in a closed position where the view to the outside was totally blocked.

The measurements were carried out under perfectly sunny and overcast conditions. The sunny day measurements were performed three times a day (i.e. in the morning, at noon and in the afternoon) between July 2-19, 2001 while the overcast measurements were carried out between the end of July and the end of August 2001. The measurements were carried out simultaneously in two rooms. One room – called the "Reference room" – was totally empty while the other room – called the "Test room" – was furnished as a typical office room. In each room, the work plane illuminance and the illuminance on lateral walls were recorded by lux meters, while the luminance of the walls and window-shade combination was measured using a calibrated CCD camera and two luminance meters.

The results of the measurements show that the shading devices studied can be placed in three distinct groups. Group 1 consists of all dark-coloured (black and brown) screens; Group 2 includes the closed venetian blind while Group 3 includes the white screens and the horizontal venetian

blind. The devices of Group 1 produced unacceptably low work plane illuminance and vertical luminance values which resulted in unsuitable luminance ratios between the task, the walls and the VDT screen. However, these devices reduced the luminance of the window (sky) to acceptable levels i.e. below 500 cd/$m^2$, most of the time. The devices of Group 3 did not prevent high window luminance but resulted in higher levels of work plane illuminance and inner wall luminance, which makes them suitable for traditional paper tasks. They also yielded high wall luminance values which resulted in some unacceptable luminance ratios between the task, walls and VDT screen. In this case, the wall behind the VDT screen and the paper task was more than three times brighter than the VDT screen.

The closed venetian blind (Group 2) was the only device which scored well on all performance indicators considered. It provided ideal illuminance levels for a combination of paper and computer work and resulted in favourable wall luminances values compared with the luminance of a standard VDT screen. However, the view to the outside was totally blocked in that case.

The study generally shows that none of the shading screens studied met all the requirements of all the performance indicators considered. The dark-coloured screens met the requirement regarding the maximum luminance in the field of view but failed to meet the requirements regarding minimum work plane illuminance levels and minimum wall luminance levels and luminance ratios between the VDT screen, the wall behind the screen and the paper task. On the other hand, the white screens did meet the requirements regarding minimum work plane illuminance levels and minimum wall luminance levels. However, they generated high luminance values at the window and high illuminances on the work plane, which may be too high for computer work.

The main conclusion is that the dark-coloured screens should be preferably used in offices where the window occupies the central field of view of the office worker and where most of the tasks are carried out on the computer. However, artificial lighting should be provided in this case (on the walls and task) and it should also be possible to pull the shading screens up when the outdoor illuminance levels are low. The white screens should be used in offices where the occupant is sitting so that the window is not in the field of view and traditional office tasks are carried out. In this case, these shading screens do prevent direct sunlight patches in the room and provide a pleasant and evenly distributed light but the view through the window is often completely blocked.

# References


AFNOR (1990). *Ergonomical Principles Applicable to the Lighting of Workplaces for Visual Comfort.* French code NF X 35-103. AFNOR (Association française de normalisation). Paris (France). ISSN 0335-3931.

Chauvel, J., Collins, B., Dogniaux, R. & Longmore, J. (1982). Glare from Windows: Current View of the Problem. *Lighting Research and Technology.* 14 (1). pp. 31-46.

Christoffersen, J., Petersen, E., Johnsen, K., Valbjørn, O, & Hygge, S. (1999). *Vinduer og dagslys - en feltundersøgelse i kontorbygninger (Windows and daylight - a post-occupancy evaluation of offices).* SBI-rapport 318. Statens Byggeforskningsinstitut. Hørsholm (Denmark). 71 pages. (in Danish).

CIBSE (1994). *Code for Interior Lighting.* CIBSE (Chartered Institution of Building Services Engineers). London (UK).

CIE (1986). *Guide on Interior Lighting. Second Edition.* Publication No 29.2. Commission Internationale de l'Éclairage (CIE). Vienna (Austria). 113 pages.

CIE (1987). *International Lighting Vocabulary.* Publication CIE No. 17.4. Commission Internationale de l'Éclairage (CIE). Vienna (Austria).

Dubois, M.-C. (2001). *Impact of Shading Devices on Daylight Quality in Offices: Simulations with Radiance.* Report TABK--01/3062. Lund University, Dept. of Construction and Architecture, Div. of Energy and Building Design. Lund (Sweden).

IES (Rea, M. S., ed.) (1993). *Lighting Handbook: Reference and Application.* Illuminating Engineering Society of North America (IESNA). 8th edition.

ISO (2000). *Ergonomic Requirements for Office Work with Visual Display Terminals (VDTs) – Part 6: Guidance on the Work Environment.* French, European and International code NF EN ISO 9241-6:1999. AFNOR (Association française de normalisation). Paris (France). 35 pages. ISSN 0335-3931.

NUTEK (1994). *Programkrav: belysning på kontor. Programkrav för god och energieffektiv bekysning på kontor.* 1994-11. Utgåva 2. Närings- och teknikutvecklingsverket (NUTEK). Stockholm (Sweden). (in Swedish).

# Appendix A

## Comparison between the CCD camera and electronic luminance meter readings

An electronic luminance meter (LMT) was mounted under the camera and recorded the luminance at the same time as the camera, but for an opening of only 1°. This region was identified on the digital picture taken by the camera, which allowed comparison of the value measured by the electronic luminance meter with the one measured by the camera only for one point in the digital image. Fig. A.1 to A.3 show the values obtained with the camera (IQcam) versus the ones measured by the electronic luminance (LMT) meter for the Reference room.

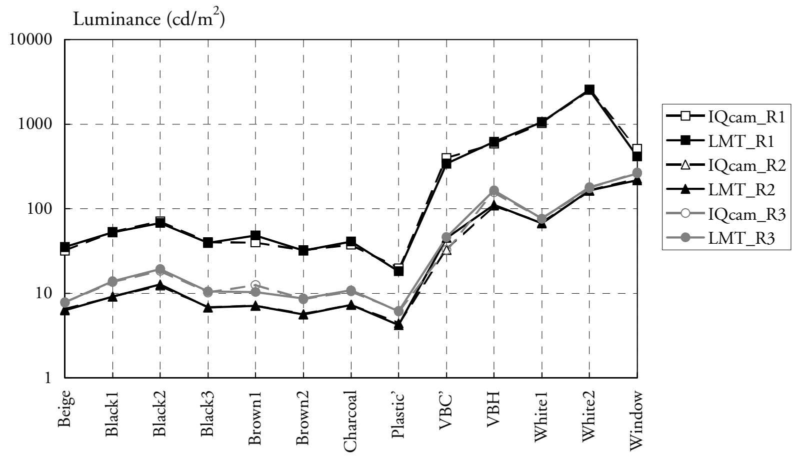



*Figure A.1* *Luminance (cd/m$^2$) measured with the CCD camera (IQcam) versus the luminance simultaneously measured with the electronic (LMT) luminance meter for the morning measurements in the Reference room.*

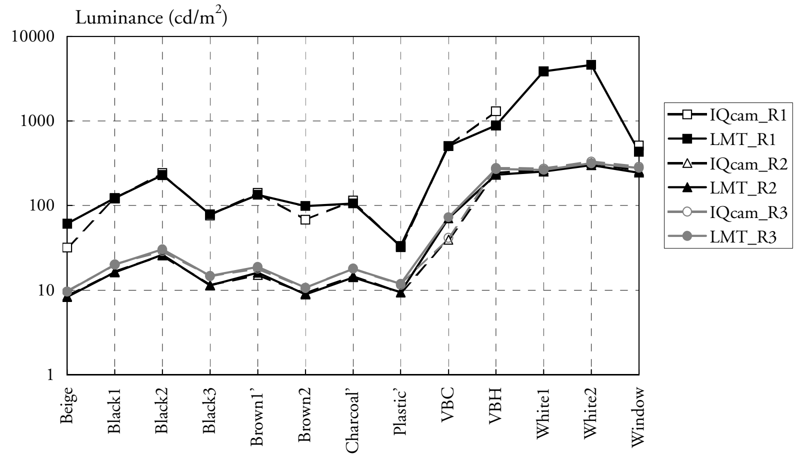



*Figure A.2* *Luminance (cd/m²) measured with the CCD camera (IQcam) versus the luminance simultaneously measured with the electronic (LMT) luminance meter for the noon measurements in the Reference room.*

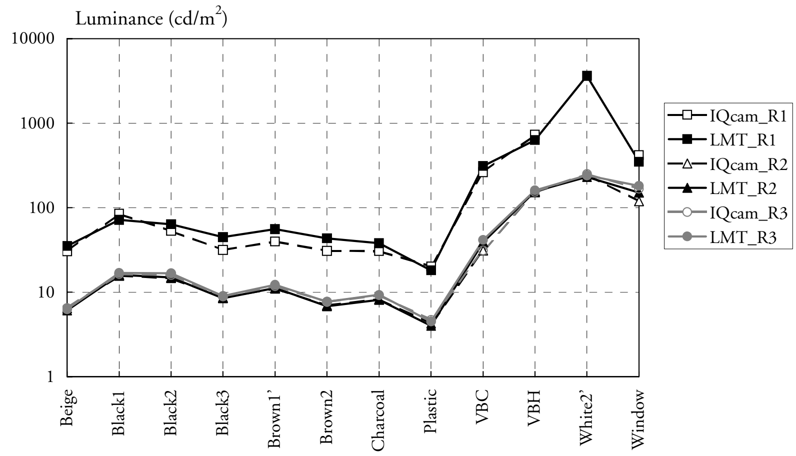



*Figure A.3* *Luminance (cd/m²) measured with the CCD camera (IQcam) versus the luminance simultaneously measured with the electronic (LMT) luminance meter for the afternoon measurements in the Reference room.*

Fig. A.1 to A.3 show that, in general, both instruments returned approximately the same value. The agreement between the two instruments was very good in the morning. At noon time, there was more divergence between measurements for the first picture (R1), and especially for the systems Beige, Brown2 and VBH. Note that the camera returned no value for White1 and White2 since the luminance was outside its dynamic range. The afternoon measurements were the ones where the correlation between the two instruments was the poorest, especially for R1. The values measured by the camera for the systems Black2, Black3, Brown1', Brown2 and Charcoal were systematically lower than the values measured by the electronic luminance meter. The most probable explanation for this slight shift is that there was a small error in identifying the point that the LMT meter was measuring on the digital image. As mentioned earlier, since this point fell onto a group of trees which had a high degree of variation in luminance, it is possible that even a small error in positioning the spot on the digital image may have resulted in large differences in luminance values. This explanation is somehow supported by the fact that it is mostly the screens that transmit light directly (which thus "see" the trees) that exhibit this shift in luminance values.

The average relative difference between the luminance values was 16 % for the first picture (R1), 7 % for the second picture (R2) and 7 % for the third picture (R3).

The relationship between the CCD camera and electronic luminance meter readings in the Test room is shown in Fig. A.4 to A.6.

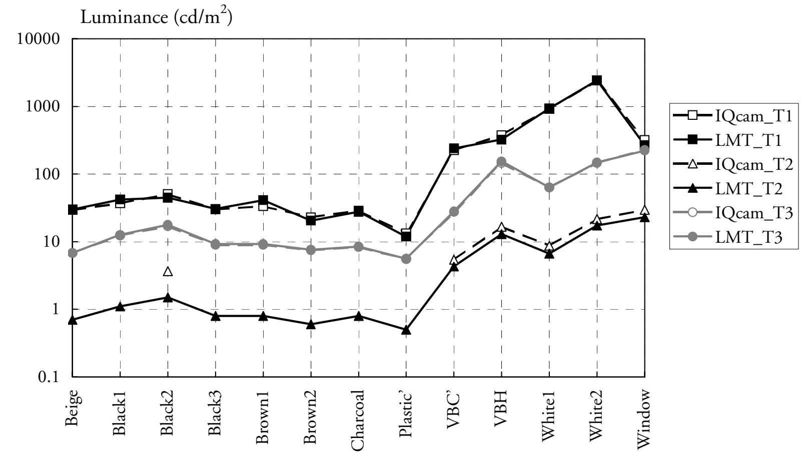



*Figure A.4* *Luminance (cd/m²) measured with the CCD camera (IQcam) versus the luminance simultaneously measured with the electronic (LMT) luminance meter for the morning measurements in the Test room.*

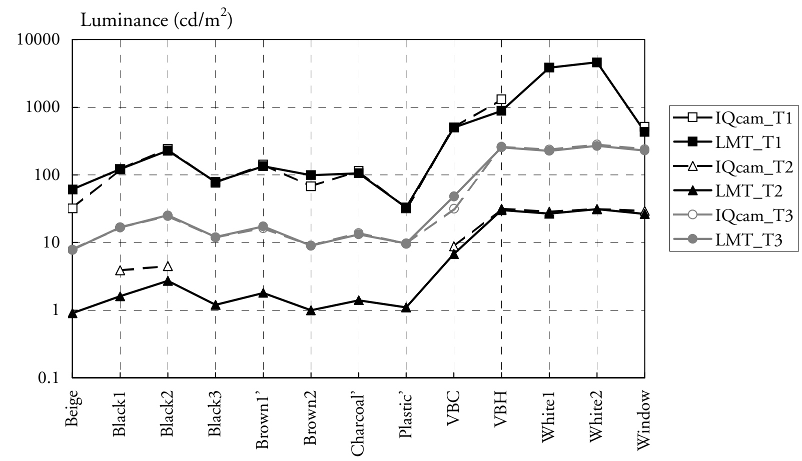



*Figure A.5* *Luminance (cd/m²) measured with the CCD camera (IQcam) versus the luminance simultaneously measured with the electronic (LMT) luminance meter for the noon measurements in the Test room.*

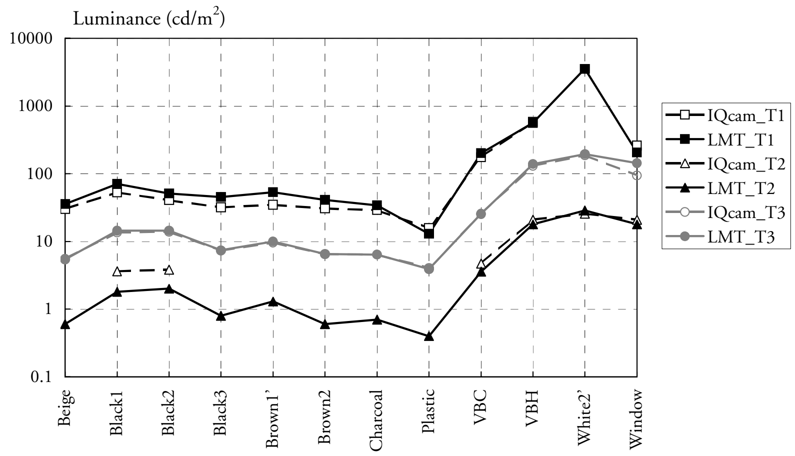



*Figure A.6* *Luminance (cd/m²) measured with the CCD camera (IQcam) versus the luminance simultaneously measured with the electronic (LMT) luminance meter for the afternoon measurements in the Test room.*

Fig. A.4 to A.6 show that, in general, there was good agreement between the two instruments. The agreement was poorer for the second picture (T2). As explained earlier in this report, this particular point fell onto a dark piece of furniture, which resulted in very low luminance values that were outside the dynamic range of the camera. Many values were simply not recorded by the camera and for the values that were recorded, the agreement was not as good since the precision of the camera was not very good in that luminance range. For the first picture (T1), the comments made for the Reference room also apply here.

The average relative difference between the luminance values was 17 % for the first picture (T1), 24 % for the second picture (T2) and 5 % for the third picture (T3).

# Appendix B

## Comparison between the CCD camera and manual luminance meter readings

The luminance measurements were completed by a measurement, with a manual luminance meter (Hagner),of the luminance of the sky seen through the window-shade combination. This extra measurement was also used to verify the validity of the measurements from the CCD camera. Fig. B.1 to B.3 show a comparison of the luminance measured with the camera with the one obtained with the manual luminance meter.

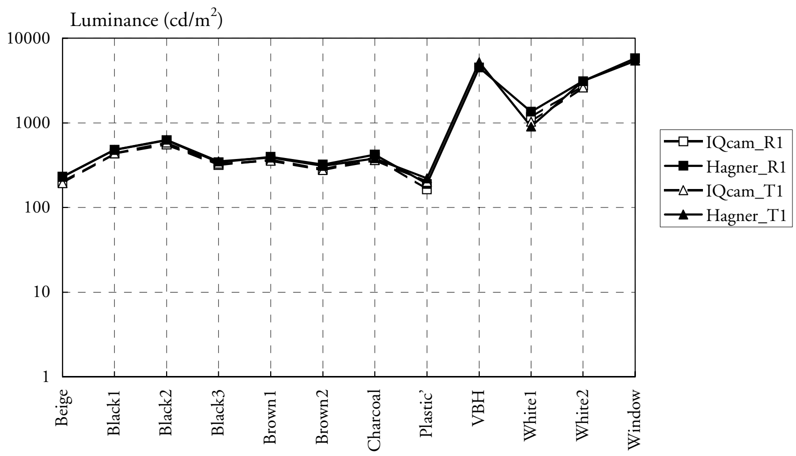



*Figure B.1* *Luminance (cd/m$^2$) measured with the CCD camera (IQcam) versus the luminance simultaneously measured with the manual luminance meter (Hagner) for the morning measurements in the Reference (R1) and Test room (T1).*

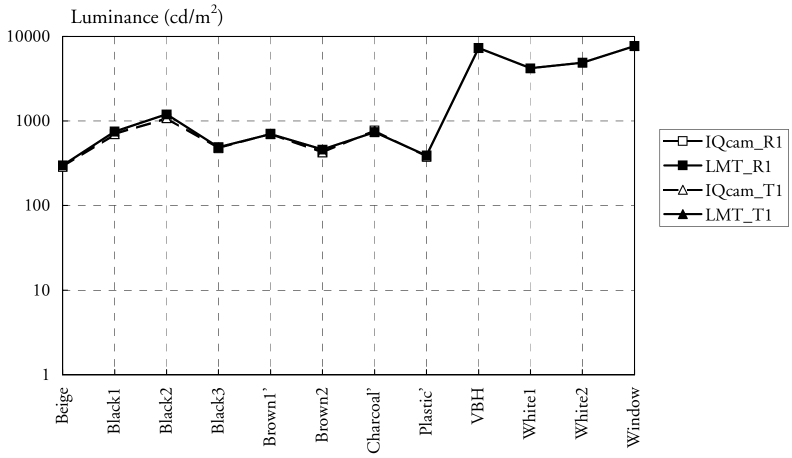



*Figure B.2* *Luminance (cd/m$^2$) measured with the CCD camera (IQcam) versus the luminance simultaneously measured with the manual luminance meter (Hagner) for the noon measurements in the Reference (R1) and Test room (T1).*

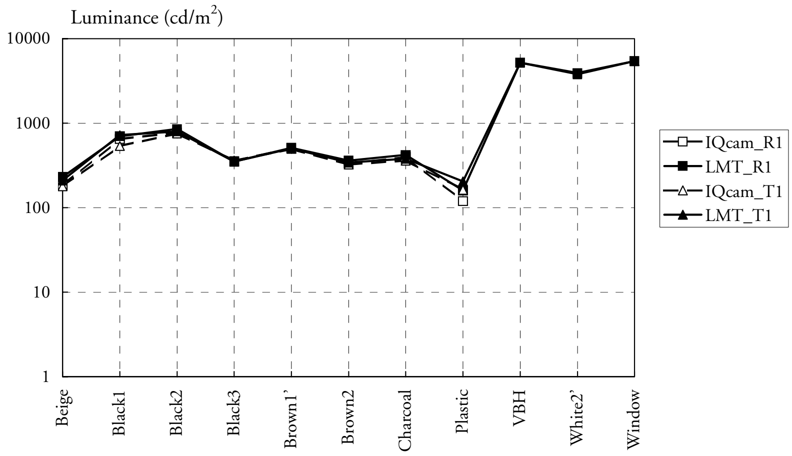



*Figure B.3* *Luminance (cd/m$^2$) measured with the CCD camera (IQcam) versus the luminance simultaneously measured with the manual luminance meter (Hagner) for the afternoon measurements in the Reference (R1) and Test room (T1).*

Fig. B.1 to B3 show that both instruments returned approximately the same value. The average relative difference between the luminance measured with the CCD camera and the manual luminance meter was around 10 % for both the Reference room and Test room. The agreement between the two instruments was exceptional at noon time. The figures also show that the values measured were the same in both rooms. Note, however, that some values for the CCD camera are missing in the figures because the luminance of the sky was beyond the dynamic range of the camera.

# Appendix C

## Comparison between the CCD camera and vertical illuminance lux meter readings

The luminance of the lateral walls was also measured by lux meters placed in the middle of the walls at three positions i.e. 0.6, 3.0 and 5.4 m from the window. The illuminance values obtained can be converted to luminance values since the wall is an almost perfect diffuse surface, using equation (3.1).

These resulting luminance values were compared with the ones measured by the camera around the same spot. Fig. C.1 to C.6 show a comparison of the values obtained with the CCD camera with the ones calculated from the lux meter values.

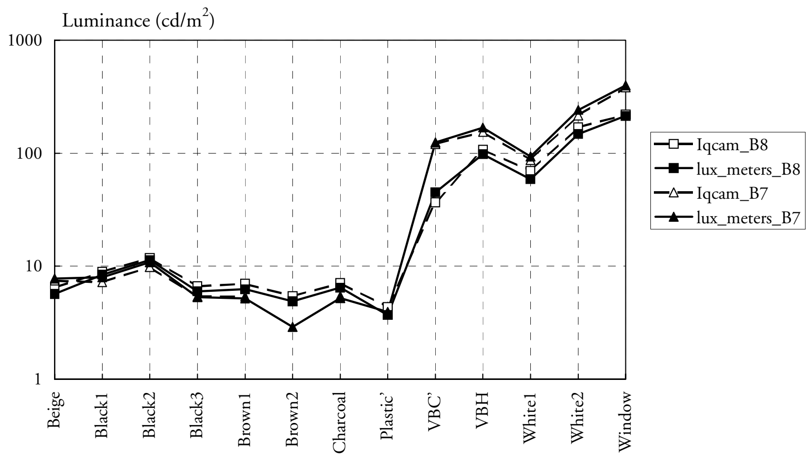



*Figure C.1* *Luminance values (cd/m²) measured with the CCD camera and the values calculated from the illuminance measured by the lux meters B7 and B8, for the morning measurements.*

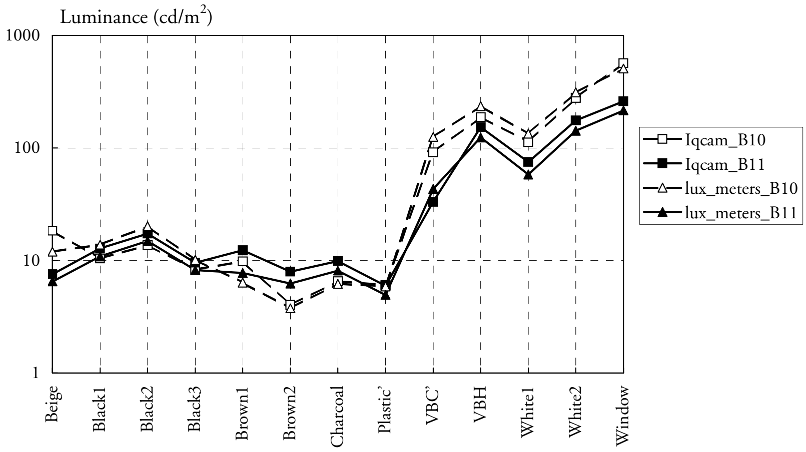



*Figure C.2* *Luminance values (cd/m²) measured with the CCD camera and the values calculated from the illuminance measured by the lux meters B10 and B11, for the morning measurements.*

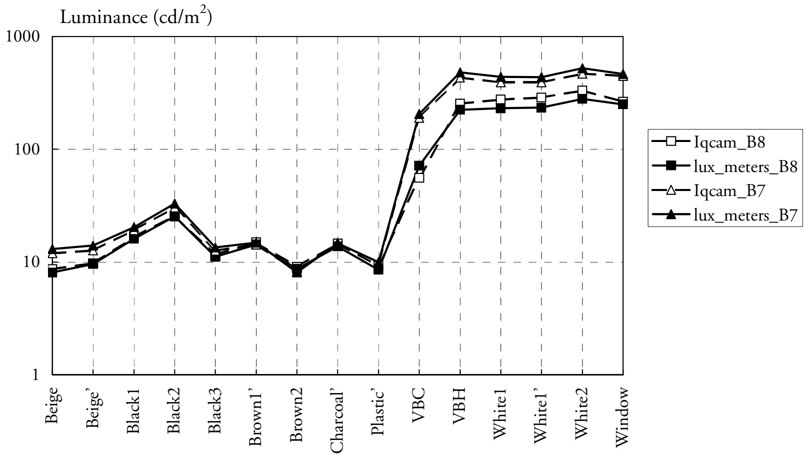



*Figure C.3* *Luminance values (cd/m²) measured with the CCD camera and the values calculated from the illuminance measured by the lux meters B7 and B8, for the noon measurements.*

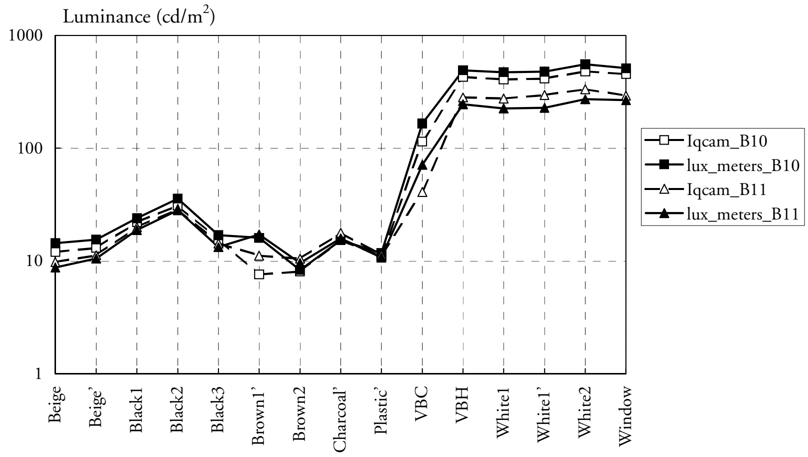



*Figure C.4* *Luminance values (cd/m²) measured with the CCD camera and the values calculated from the illuminance measured by the lux meters B10 and B11, for the noon measurements.*

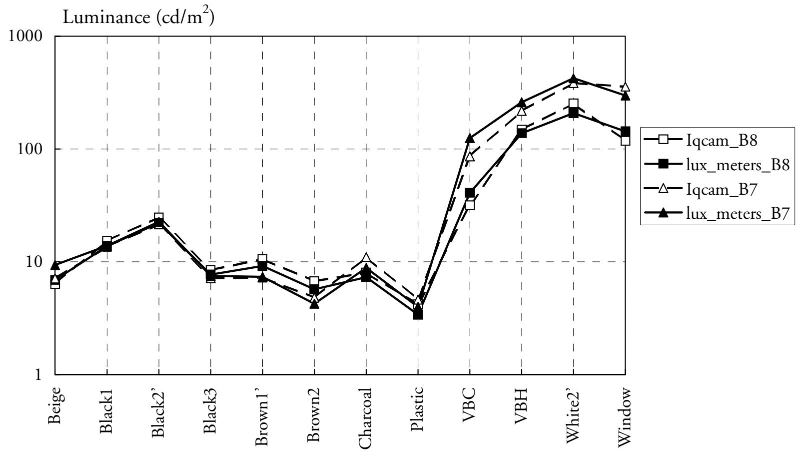



*Figure C.5* *Luminance values (cd/m²) measured with the CCD camera and the values calculated from the illuminance measured by the lux meters B7 and B8, for the afternoon measurements.*

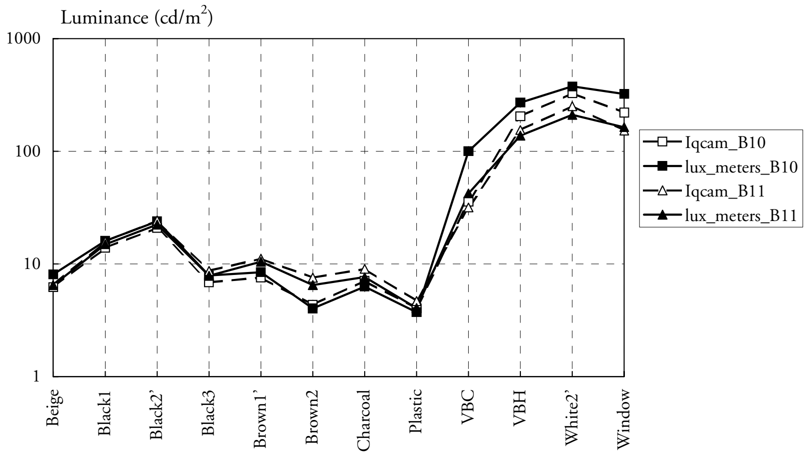



*Figure C.6* *Luminance values (cd/m²) measured with the CCD camera and the values calculated from the illuminance measured by the lux meters B10 and B11, for the afternoon measurements.*

Fig. C.1 to C.6 show that the correlation between the two instruments is rather good despite the fact that the luminance was not measured at the same place. The illuminance was measured at 1.5 m from the floor while the luminance in the CCD camera was taken at 1.125 and 1.875 m from the floor. Note that the values shown in Fig. C.1-C.6 are averages between the luminance measured at 1.125 and 1.875 m.

The average absolute relative difference between the CCD camera and the lux meter readings was 11 % for detector B7, 7 % for detector B8, 25 % for detector B10 and 17 % for detector B11. The difference was higher for the lux meters located on the west wall, for all measurements, i.e. morning, noon and afternoon, which suggests that this difference was due to a systematic error.

# Appendix D

## Comparison between the Reference (empty) and Test (furnished) room

The impact of the furniture on the work plane illuminance was quite substantial. Fig. D.1 to D.3 show the absolute relative difference between the illuminance values measured in the Reference room (detectors A1-A4) and in the Test room (detectors B1-B4). The absolute relative difference was calculated as follows:

$$|RD| = |(E_R - E_T)|/E_R \qquad \text{(D.1)}$$

where

$E_R$ is the illuminance (lx) in the Reference room,
$E_T$ is the illuminance (lx) in the Test room.

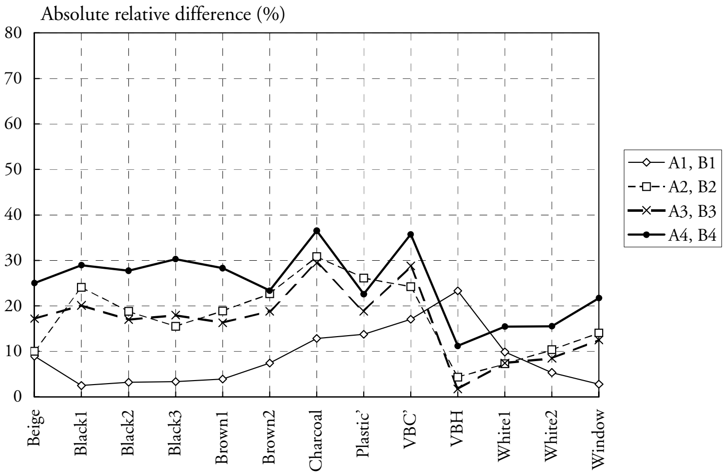



*Figure D.1* *Absolute relative difference (%) between the work plane illuminance values measured in the Reference and Test room for detectors A1-B1 to A4-B4, morning measurements.*

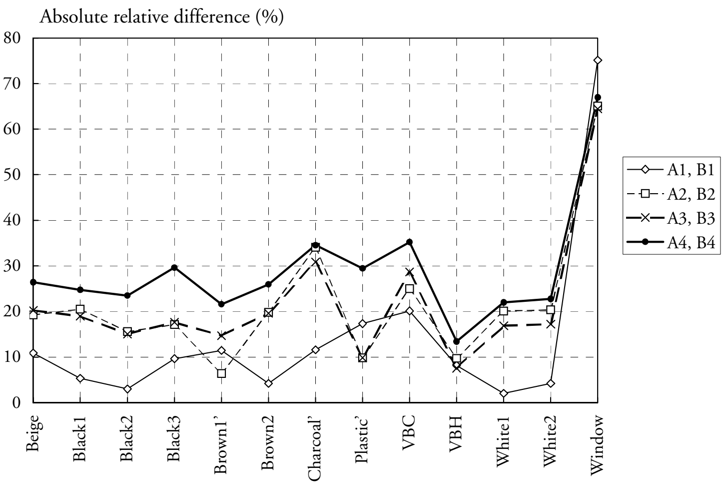



*Figure D.2* *Absolute relative difference (%) between the work plane illuminance values measured in the Reference and Test room for detectors A1-B1 to A4-B4, noon measurements.*

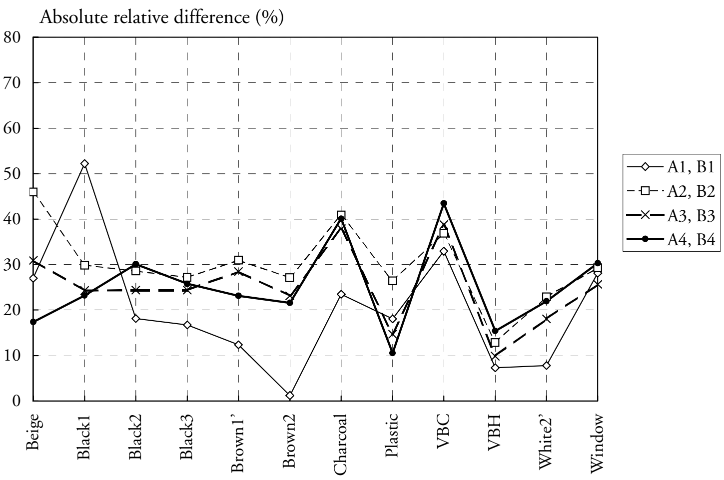



*Figure D.3* *Absolute relative difference (%) between the work plane illuminance values measured in the Reference and Test room for detectors A1-B1 to A4-B4, afternoon measurements.*

Fig. D.1 to D.3 show that the difference between the two rooms is not systematic for the detectors closest to the window, in particular for detectors A1-B1 and A2-B2. However, the difference becomes more systematic further away from the window i.e. for detectors A3-B3 and A4-B4. For these detectors, the illuminance in the Test room was 21 % and 26 % respectively lower on average than in the Reference room.

The detectors closest to the window were placed slightly (about 15 cm) west of the central row of detectors. Moreover, they were shaded by the computer in the morning. These factors, plus the fact that they were closer to the window, explain why the difference between the measurements in the Reference and Test room are not as systematic as for the detectors placed further away in the room. Detectors placed further away in the room receive a more substantial part of their illumination from the internally reflected light component.

The luminance values were in general lower in the Test room than in the Reference room, as expected. The relative difference varied between shading systems and the position of the luminance spot studied. An average relative difference was calculated for each row of luminance spots, for the morning, noon and afternoon measurements (Table D.1).

Table D.1 Absolute average relative difference (%) in luminance values between the Reference and the Test room.

| **Height from the floor (m)** | Absolute relative difference (%) | | | |
|---|---|---|---|---|
| | Morning | Noon | Afternoon | **Average** |
| **0.375** | 34 | 32 | 38 | **34** |
| **1.125** | 29 | 27 | 31 | **29** |
| **1.875** | 19 | 16 | 22 | **19** |
| **2.625** | 26 | 15 | 25 | **22** |
| **Average** | 27 | 23 | 29 | **26** |

Table D.1 shows that the average relative difference was larger for detectors at 0.375 and 1.125 m from the floor than for the other detectors. Moreover, the relative difference was generally larger in the morning and afternoon than at noon time. The overall average difference in luminance between the Reference room and Test room was 26 % i.e. the luminance in the Test room was on average 26 % lower than in the Reference room. Fig. D.4 shows an example of the values obtained in each room at noon time.

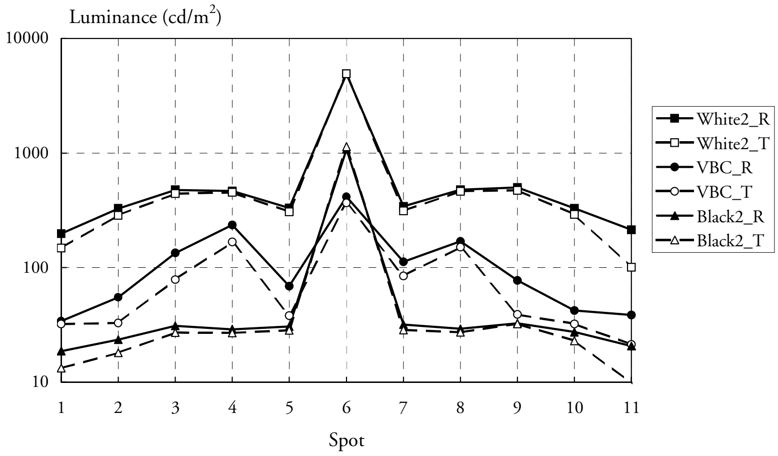



*Figure D.4* *Luminance values (cd/m²) measured in the Reference and Test rooms for a few shading systems studied.*