Absorption
Transformation of radiant energy to a different form of energy by the intervention of matter.

Adaptation
The process by which the state of the human visual system is modified by previous and present exposure to stimuli that may have various luminances, spectral distributions, and angular subtenses.

Altitude
The angular distance of the sun measured upward from the horizon on the vertical plane that passes through the sun. Altitude is measured positively from horizon to zenith from 0° to 90°.

Angle of Incidence
The angle between a ray of light falling on a surface and a line perpendicular to the surface.

Atmospheric Turbidity
The scattering of solar radiation caused by air molecules, the scattering and absorption of solar radiation by larger particles known as aerosols, and the absorption of solar radiation by atmospheric gases and water vapour in the atmosphere. Atmospheric turbidity is usually expressed as the ratio of the total attenuation from molecules and aerosols in the atmosphere to that of molecules alone, using coefficients or optical thicknesses of molecular and particulate atmospheres. Atmospheric turbidity values
of 3 to 6 are common even on days described as clear. A value of unity is equivalent to a Rayleigh atmosphere in which the size of particles is small compared with the wavelength of the radiation.

**Atrium**

An interior light space enclosed laterally by the walls of a building and covered with transparent or translucent material that permits light to enter interior spaces through pass-through components.

**Azimuth**

The azimuth of the sun is the angle between the vertical plane containing the sun and the vertical plane oriented to the north (direction of origin).

**Brightness**

The visual sensation by which an observer registers the degree to which a surface appears to emit or reflect more or less light. This subjective sensation cannot be measured in absolute units; it describes the appearance of a source or object.

**Candela**

The unit of luminous intensity. The luminance of a full radiator at the temperature of solidification of platinum is 60 candelas / cm².

**Candela Per Square Meter**

A unit of luminance in a particular direction recommended by the Commission Internationale de L’Éclairage (CIE).

**CIE Standard Clear Sky**

Cloudless sky for which the relative luminance distribution is described in Publication CIE No. 22 (TC 4.2) 1973 Commission Internationale de L’Éclairage (CIE).

**CIE Standard Overcast Sky**

A completely overcast sky for the luminance (cd/m²) of any point in the sky at an angle of elevation $\gamma$ above the horizon, is assumed to be given by the relation:

$$L\gamma = \frac{L_z (1+2\sin\gamma)}{3}$$

where $L_z$ is the luminance at the zenith.

**Clerestory**

Daylight opening in the uppermost part of an exterior wall.
Contrast

The subjective assessment of the difference in appearance of two parts of a field of view seen simultaneously or successively. It can be defined objectively as:

\[
\frac{(L_1 - L_2)}{L_1}
\]

where \(L_1\) and \(L_2\) are the luminances of the background and object, respectively.

Daylight

Visible global radiation. Daylight is the sum of sunlight and skylight.

Daylight Factor

Ratio, at a point on a given plane, of the illuminance that results from the light received directly or indirectly from a sky of assumed or known luminance distribution to the illuminance on a horizontal plane that results from an unobstructed hemisphere of this sky. The contribution of direct sunlight to both illuminances is excluded.

Daylight Opening

Area, glazed or unglazed, that is capable of admitting daylight to an interior.

Diffuse Illuminance From the Sky

Illuminance from the sky received on a horizontal plane from the whole hemisphere, excluding direct sunlight.

Diffuser

A device object or surface used to alter the spatial distribution of light.

Diffuse Reflection

The process by which incident flux is redirected over a range of angles.

Diffuse Transmission

The process by which the incident flux passing through a surface or medium is scattered.

Diffuse Transmittance

The ratio of the diffusely transmitted luminous flux leaving a surface or medium to the total incident flux.

Diffusion

The scattering of light rays so that they travel in many directions rather than in parallel or radiating lines.
Disability Glare
Excessive contrast, especially to the extent that visibility of one part of the visual field is obscured by the eye’s attempt to adapt to the brightness of the other portion of the field of view; visibility of objects is impaired.

Discomfort Glare
Glare that causes annoyance without physically impairing a viewer’s ability to see objects.

Emission
Release of radiant energy.

Fenestration
Any opening or arrangement of openings in a building for the admission of daylight or air.

Glare
A visual condition which results in discomfort, annoyance, interference with visual efficiency, or eye fatigue because of the brightness of a portion of the field of view (lamps, luminaires, or other surfaces or windows that are markedly brighter than the rest of the field). Direct glare is related to high luminances in the field of view. Reflected glare is related to reflections of high luminances.

Goniophotometer
Photometer for measuring the directional light distribution characteristics of sources, luminaires, media, or surfaces.

Integrating Sphere
Hollow sphere whose internal surface is a diffuse reflector that is as non-selective as possible.

Illuminance
The luminous flux incident on a surface per unit area. The unit is lux, or lumens per square foot.

Indirect Lighting
Illumination achieved by reflection, usually from wall and/or ceiling surfaces.

Latitude
Geographical latitude is the angle measured in the plane of the long meridian between the equator and a line perpendicular to the surface of the Earth through a particular point.
Light
Radiant energy evaluated according to its capacity to produce visual sensation.

Light Duct
An element of a building that carries natural light to interior zones. Duct surfaces are finished with highly reflective materials.

Longitude
The angular distance from the meridian through Greenwich, England, to the local meridian through a particular point. Longitude is measured either east or west from Greenwich through 180° or 12 hours.

Lumen
The unit of luminous flux. It is equal to the flux through a unit of solid angle (steradian) from a uniform point source of one candela or the flux on a unit surface all points of which are at a unit distance from a uniform point of one candela.

Luminaire
A complete lighting unit (fixed or portable) that distributes, filters, or transforms the light given by a lamp or lamps and that includes all the components necessary for mounting and protecting the lamps and connecting them to the supply circuit.

Luminance
The luminous intensity of any surface in a given direction per unit or projected area of the surface as viewed from that direction.

Lux
The International System (SI) unit of illumination. It is the illumination on a surface one square metre in area on which there is a uniformly distributed flux of 1 lumen.

Obstruction
Surfaces outside the building that obstruct direct view of the sky from a reference point.

Overcast Sky
Sky completely covered by clouds with no sun visible.

Radiation
Energy in the form of electromagnetic waves or particles.

Reflectance
The ratio of light reflected to incident light.
**Reflection**
Process by which radiation is returned by a surface or a medium without change of frequency of its monochromatic components.

**Reflector**
A device that returns incident visible radiation; used to alter the spatial distribution of light.

**Refraction**
Change in direction of propagation of radiation determined by change in the velocity of propagation as radiation passes through an optically non-homogeneous medium or from one medium to another.

**Relative Sunshine Duration**
Ratio of actual time to possible time when the sun is not obscured by clouds.

**Shading**
Use of fixed or movable devices to block, absorb, or redirect incoming light for purposes of controlling unwanted heat gains and glare.

**Shading Coefficient**
The dimensionless ratio of the total solar heat gain from a particular glazing system to that for one sheet of clear, 3-mm, double-strength glass.

**Shading Device**
Device used to obstruct, reduce, or diffuse the penetration of direct sunlight.

**Skylight**
An opening situated in a horizontal or tilted roof.

**Toplighting**
Daylight that enters through the upper portion of an interior space such as a clerestory or skylight.

**Translucent Glass**
A glass with the property of transmitting light diffusely.

**Transmission**
Passage of radiation through a medium without change of frequency of its monochromatic components.
Transmittance
Ratio of the transmitted radiant or luminous flux to the incident flux in the given conditions.

Veiling Reflections
Reflections that reduce the contrast between the task/object and the background when extremely bright reflections of light sources appear on the task object itself.

Window
Daylight opening on a vertical or nearly vertical area of a room envelope.

Chapter 1.: Introduction

Chapter 2.: Daylight in Building Design


References and Bibliography 8.2.
Chapter 3.: Performance Parameters


Chapter 4.: Daylighting Systems

4.3.: Light Shelves


4.4.: Louvers and Blinds Systems


4.5.: Prismatic Panels


4.6.: Laser-Cut Panels


4.7.: Angular Selective Skylight (Laser-Cut Panel)


4.8.: Light-Guiding Shades


4.9.: Sun-directing Glass

4.10.: Zenithal-Light Guiding Glass with Holographical Optical Elements


4.11.: Directional Selective Shading Systems Using Holographical Optical Elements (HOEs)


4.12.: Anidolic Ceilings

Courret, G. 1999. Systèmes anidoliques d’éclairage naturel, Thèse no. 2026, DA/EPFL.


4.13.: Anidolic Zenithal Openings


4.14.: Anidolic Solar Blinds


Chapter 5.: Daylight-Responsive Controls


Hunt, D.R.G. 1980 *Predicting artificial use — a method based upon observed patterns of behaviour.* Lighting Research and Technology 12 (1) 7-14.


Chapter 6.: Design Tools


Michel, L. 1998. IEA SHC Task 21 Scale models - Daylighting systems evaluation. IEA SHC Task 21 working document, EPFL.


Appendices

8.3.: Optical Characteristics of Daylighting Materials


CIE Publ. No. 53 (TC - 2.2), Methods of characterizing the performance of radiometer and photometer, 1982.


8.3. Optical Characteristics of Daylighting Materials

This appendix describes methods used to present and format measured optical performance data for daylighting systems, including 1) directional luminous transmittance measurements and 2) bi-directional transmittance distribution measurements. These data can be used in daylight simulation programs such as those described in Appendix 8.9 (on the CD-ROM).

8.3.1. Geometrical Description

In order to characterise any daylighting system with respect to different incident and observation angles, a coordinate system needs to be defined.

The origin is placed in the daylighting element. The z-axis will be orthogonal to the element’s surface. Directions are defined by the azimuth angle $\varphi$ and altitude angle $\theta$ (similar to spherical coordinates).

An angle’s index indicates whether the angle is related to the incident or the observation direction; index 1 is the incident direction and 2 is the observation direction.

The range of the angle $\varphi$ is from $0^\circ$ to $360^\circ$; $\theta$ varies between $0^\circ$ and $90^\circ$ for light incidence and from $90^\circ$ to $180^\circ$ for light transmittance.
The relative position of any daylight element to this coordinate system is of significant impact to the measurement results. Therefore, not only the coordinate system needs to be well defined but also the orientation of the sample. If no additional information about the orientation is given in the measurement setup description, the following rules apply to the adjustment:

- The sample plane is parallel to a vertical window plane, i.e. the z-axis is pointing horizontally.
- The orientation of the sample within the x-y-plane is exactly like its orientation in the real daylight system, e.g. the linear structure of a laser-cut panel is usually horizontal, so $\phi_1 = 0^\circ$ in the experimental setup will show horizontal structures as well.
- The positive z-axis is the outside direction of the sample.

### 8.3.2. Luminous Transmittance (Directional) Measurements

Luminous transmittance measurements as a function of light incidence describe the ratio of transmitted luminous flux to the incident luminous flux. Since the two angles $\phi_1$ and $\theta_1$ change over a wide range, a large quantity of data has to be stored and, in subsequent steps, presented. A detailed description of the data format and the presentation of the results are given in the following sections.

#### Data Format

One of the most important aspects in storing any kind of data that should be accessed by many users is to have a device-independent format. Therefore, an ASCII file is suggested for the measurement results of luminous transmittance measurements. Such files can easily be read on nearly any operating system.

Since the results of the measurements sometimes show very high gradients, it is often not sufficient to store the data in a uniform incident angle grid. It makes a lot more sense to scan areas of interest with a smaller grid. To keep the file size quite small, such a grid does not necessarily need to be used for regions where the results do not change a lot. A uniform grid therefore allows both, a good description of the daylight element and no waste of disk space.

**Note:** A uniform grid is just a special case of a non-uniform grid. It is not forbidden to save the data in a uniform grid. In some cases (diffuse transmitting elements) it is recommended to have a uniform grid.

The data format for luminous transmittance measurements can be divided into two parts: header section and data section. The header contains basic information about the daylighting element and its symmetry (see example for details). Within the data section the range of the incident angles are given. After that each line of the file contains three values separated by the so-called tab-character (ASCII code 9). The first two values correspond to the incident angles $\phi_1$ and $\theta_1$. The third value is the luminous transmittance.
In the following lines the beginning of a typical luminous transmittance measurement file with a non-uniform grid is given:

**Note:** The lines in square brackets do not belong to the data file.

### [HEADER SECTION]

```
#material: prismatic film
#manufacturer: 3M
#symmetry indicator: 0 no symmetry (phi_1 = 0°...360°)
#          1 rotary symmetry (only for one phi_1)
#          2 symmetry to phi=0° and phi=180° (phi_1 = 0°...180°)
#          3 symmetry to phi=90° and phi=270° (phi_1 = -90°...90°)
#          4 symmetry to phi=0° & phi=180° and to phi=90° & phi=270° (phi_1=0°...90°)
#measurements done at TU-Berlin Institute of Electronics and Lighting Technology
#measurements by Ali Sit, Berit Herrmann and Sirri Aydinli
#date of measurements: 3. March 1998
#contact aydinli@ee.tu-berlin.de
#light incidence:
#phi_1-range: 0°...90° (azimuth)
#theta_1-range: 0°...70° (altitude)
#light transmittance for hemispherical light incidence : 0.49
```

### [DATA SECTION]

```
#data
#phi_1   theta_1  tau
0.000000e+000 0.000000e+000 2.503987e-002
0.000000e+000 2.500000e+000 2.500000e-002
0.000000e+000 5.000000e+000 2.500000e-002
0.000000e+000 7.500000e+000 2.424242e-002
0.000000e+000 1.000000e+01  2.424242e-002
0.000000e+000 1.250000e+01 2.272727e-002
0.000000e+000 1.500000e+01 2.272727e-002
0.000000e+000 2.000000e+01 2.121212e-002
0.000000e+000 2.500000e+01 2.045455e-002
0.000000e+000 3.000000e+01 1.893939e-002
0.000000e+000 3.500000e+01 1.818182e-002
```

**Presentation of Measurement Results**

Due to the fact that two parameters are changed during the luminous transmittance measurements, a lot of data are obtained during the measurement. By looking at the values only, one cannot really see the information contained in the measurements. A graphical way to display the results is much more efficient, because the shape of a luminous transmittance body points out visually angle regions of interest.

**Luminous Transmittance for Hemispherical Light Incidence**

The luminous transmittance for hemispherical light incidence $\tau_{\text{diff}}$ is defined as the luminous transmission for an illumination with nearly uniform luminance from the hemisphere.

This quantity could be measured using a hemisphere (or sphere) to illuminate the sample. It can also be derived from the integration of the luminous transmittance measurements:
For a rotation symmetrical light transmittance:

\[
\tau_{\text{df}} = \frac{1}{2\pi} \int_{\phi_1=0}^{2\pi} \int_{\theta_1=0}^{\pi} \tau(\phi_1, \theta_1) \cdot \sin(2\theta_1) \cdot d\theta_1 \cdot d\phi_1
\]

Filenames

All the data as well as the presentation of the sample measurements are included on the CD-ROM to this book. All measurements are put in one directory “PerformanceData/Directional” containing the data files (text files) and one WINWORD document which includes the presentation of the measurement results.

E.g. the filename “tub_3m.txt” contains the measurement results of the 3M-optical lighting film that were done at TUB.

8.3.3. Bi-directional Measurements

In contrast to luminous transmittance measurements, bi-directional measurements do not only change the incident light direction but scan the observation angles as well. The Bi-directional Transmittance Distribution Function (BTDF) is the spatial distribution of the luminance coefficient \( q(\varphi_2, \theta_2) \). In theory, the integral value of the transmitted luminous flux calculated from the bi-directional data for a given light incidence corresponds to the value obtained by the luminous transmittance measurements.

\[
\tau(\varphi_1, \theta_1) = \frac{1}{2} \int_{\varphi_2=0}^{2\pi} \int_{\theta_2=0}^{\pi} q(\varphi_2, \theta_2) \cdot \sin(2\theta_2) \cdot d\theta_2 \cdot d\varphi_2
\]

Much more data need to be stored since four parameters change their values. As a matter of fact, the presentation of bi-directional measurements is more complicated.

Light Incidence

It is agreed upon to limit the angles of light incidence according to the sky luminance distribution by Tregenza. This leads to 145 different light incidence directions which are shown in the figure and the table below.
Note: For rotation symmetrical samples, only measurements for $\theta_1 = 0^\circ$, $12^\circ$, $24^\circ$, $36^\circ$, $48^\circ$, $60^\circ$, $72^\circ$ and $84^\circ$ need to be done.

**Data Format**

In order to store the measurement results, all the aspects of the data format for luminous transmittance measurements need to be taken into account (see also 8-3.2 Data Format), i.e. the file should be in ASCII-format for device independence. The header section contains all the information about the measurement setup and the sample. It is recommended to have a single file for each light incidence rather than one file for the whole measurement. Since the data cannot be presented as a whole anyway, there is no need for storing the measurement results in one huge file. Further computation of the data becomes easier. The data section contains 3 columns in every line which are each separated by the tab character (ASCII code 9).

The solution of the light incident angles is given by the sky luminance distribution by Tregenza (see 8-3.3 Light Incidence). In order to minimise the disk space for the file without
losing important information, a non-uniform grid of observation angles is acceptable. It is recommended to scan areas of high gradients in measurement values with an angle resolution of at least 1°.

Example:

Note: The lines in square brackets do not belong to the data file.

[HEADER SECTION]

#material: sun directing glass (Lumitop)
#manufacturer: Yegla
#isym=3 : symmetry indicator: 0 no symmetry (phi_l = 0°...360°)
# 1 rotary symmetry (only for one phi_l)
# 2 symmetry to phi=0° and phi=180° (phi_l = 0°...180°)
# 3 symmetry to phi=90° and phi=270° (phi_l = 90°...270°)
# 4 symmetry to phi=0° & phi=180° and to phi=90° & phi=270° (phi_l=0°...90°)
#measurements done at TU Berlin Fachgebiet Lichttechnik, TUB
#measurements and processing by Berit Herrmann, Sirri Aydinli
#date of measurement: 29. September 1998
#contact ayydini@ee.tu-berlin.de for details
#light incidence:
#phi_1: 0° (azimuth)
#theta_1: 0° (altitude)
#light transmittance: 0.45

(DATA SECTION)

#data
#phi theta_2 btdf
0.000000e+000 9.690000e+001 2.497359e+002
0.000000e+000 9.490000e+001 2.619607e-002
0.000000e+000 1.028000e+002 2.703650e-002
0.000000e+000 1.061000e+002 2.159965e-002
0.000000e+000 1.096000e+002 2.550889e-002
0.000000e+000 1.130000e+002 1.751997e-002
0.000000e+000 1.164000e+002 2.309398e-002
0.000000e+000 1.198000e+002 1.721820e-002
0.000000e+000 1.233000e+002 1.870304e-002
0.000000e+000 1.266000e+002 2.583353e-002
0.000000e+000 1.300000e+002 1.996848e-002
0.000000e+000 1.335000e+002 2.610528e-002
0.000000e+000 1.369000e+002 4.101757e-002
0.000000e+000 1.403000e+002 5.560827e-002
0.000000e+000 1.437000e+002 6.901417e-002
....

END
Presentation of Measurement Results

Since there are four parameters for the bi-directional measurements, it is hard to present the results in a single plot. The system chosen here will include both a spatial distribution of the BTDF using spherical coordinates and the direction of the incident light (where required additional views are given).

Filenames

Bi-directional measurements collect a huge amount of data. A lot of files are created during the specification of a single material. Therefore, one should be careful with choosing the filenames. All the information about a sample and the light incidence is already included in the file’s header section, but for convenience reasons, it is useful to put the filenames into a system. The filename contains four pieces of information: the institute carrying out the measurements, the material, and the light incidence angles $\theta_1$ and $\phi_1$.

All the data as well as the presentation of each sample measurement are included on the CD-ROM to this book. All the files necessary to characterise a sample are put together in a directory, e.g. “PerformanceData/Bi_directional/ Plexiglas” or “PerformanceData/Bi_directional/SunDirectingGlass”. For each light incidence there is one text file. The presentation of the measurement results is put into a WINWORD document file.

E.g. the filename "tub_sdg_36_40.txt" contains the measurement results of the sun-directing glass that were done at TUB. The light incidence was: $\theta_1 = 36^\circ$ and $\phi_1 = 40^\circ$. The corresponding presentation of this data can be found in the file “tub_sdg.doc”.
Daylight measurements of different daylighting systems were conducted in Norway, Denmark, Germany, the United Kingdom, Austria, Switzerland, the United States, and Australia.

8.4.1. Technical University of Berlin (TUB), Germany
The experimental assessment of the daylighting systems was carried out in three unfurnished mock-up offices at the Technical University of Berlin (TUB). TUB is located in the centre of Berlin (latitude 52°N, longitude 13°E).
Geometry
The mock-up offices at TUB consist of 3 rooms (A, B, and D) with identical area. The test rooms are orientated 6° east of due south with some outside obstructions to the southeast. Each room has 3 separated windows and the sill height is 0.95 m above the interior floor level.

![Diagram of mock-up offices](image)

<table>
<thead>
<tr>
<th>Test room: TUB</th>
<th>Length</th>
<th>Width</th>
<th>Height</th>
<th>Window area</th>
<th>Glazed area</th>
<th>Occupied</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geometry</td>
<td>4.70 m</td>
<td>3.50 m</td>
<td>3.00 m</td>
<td>7.00 m²</td>
<td>5.30 m²</td>
<td>No</td>
</tr>
</tbody>
</table>

Material Photometric Properties
The rooms are unfurnished with light-coloured surfaces (walls - grey, floor - grey, ceiling - white).

<table>
<thead>
<tr>
<th>Test room: TUB</th>
<th>Reflectance</th>
<th>Transmittance of glazing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surfaces</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Walls</td>
<td>50 %</td>
<td>70 %</td>
</tr>
<tr>
<td>Floor</td>
<td>20 %</td>
<td>80 %</td>
</tr>
<tr>
<td>Ceiling</td>
<td>80 %</td>
<td>80 %</td>
</tr>
</tbody>
</table>

**Note:**
- \( \tau_{\text{dif}} \) = transmittance for hemispherical irradiation;
- \( \tau_{\perp} \) = transmittance for normal irradiation;
- U-value in W/m²K.
Equipment for Measurement

All sensors used for interior and exterior illuminance measurements were photometer heads from PRC Krochmann and LMT GmbH, Berlin. Interior horizontal illuminance levels were measured in a grid (12 sensors) at a work plane height of 0.85 m. All sensors were connected to a data acquisition system (Delphin Instruments/Keithley) by use of PC board, and the data acquisition software was developed by TUB. Exterior illuminance measurements included global horizontal, shielded vertical (north, east, south, west) luminance distribution of the sky (sky scanner PRC, Krochmann GmbH, Berlin). Additional interior measurements were carried out by use of a CCD-Camera (TechnoTeam GmbH, Ilmenau).
8.4.2. Danish Building Research Institute (SBI), Denmark

The experimental assessment of daylight systems was carried out in two unfurnished mock-up offices at the Danish Building Research Institute (SBI). SBI is located north of Copenhagen (latitude 56°N, longitude 12°E).

Geometry

The mock-up offices at SBI consist of 2 rooms with identical area. The test rooms are orientated 7° east of due south with some outside obstructions to the west. Each room has windows in full height of the facade, but the lower part of the windows were covered during the measurements (sill height, 0.78 m above the interior floor level).

<table>
<thead>
<tr>
<th>Geometry</th>
<th>Length</th>
<th>Width</th>
<th>Height</th>
<th>Window area</th>
<th>Glazed area</th>
<th>Occupied</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test room: SBI</td>
<td>6.00 m</td>
<td>3.60 m</td>
<td>3.00 m</td>
<td>7.80 m²</td>
<td>6.60 m²</td>
<td>No</td>
</tr>
</tbody>
</table>

Material Photometric Properties

The rooms are unfurnished with light-coloured surfaces (walls - white, floor - light grey, ceiling - white).

<table>
<thead>
<tr>
<th>Test room: SBI</th>
<th>Reflectance</th>
<th>Transmittance of glazing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surfaces</td>
<td>Reflectance</td>
<td>Transmittance</td>
</tr>
<tr>
<td></td>
<td>Walls</td>
<td>Floor</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>79 %</td>
<td>29 %</td>
</tr>
</tbody>
</table>

Note: $t_{\text{dir}} =$ transmittance for hemispherical irradiation; $t_{\perp} =$ transmittance for normal irradiation; U-value in W/m²K.
Equipment for Measurement

All sensors used for interior and exterior illuminance measurements were light-sensitive silicon diodes from Hagner, Sweden. Interior horizontal illuminance levels were measured in the centre line perpendicular to the window (6 sensors) at a work plane height of 0.85 m. All sensors were connected to a data acquisition system (Keithley) and the data acquisition software was developed by SBI. Exterior measurements included global horizontal and shielded vertical sky (south) illuminance.
8.4.3. Norwegian University of Science and Technology (NTNU), Norway

The experimental assessment of daylight systems was carried out in 5 (daily) occupied office rooms. The office rooms are situated in Sandvika, near Oslo, within the administrative building of the local energy company, Energiselskapet Asker og Bærum (latitude 59°N, longitude 11°E).

Geometry

The offices consist of 6 rooms with identical area. The test rooms have almost identical design, but every second room is laterally reversed (rooms 2, 4 and 6) compared to the reference room. The test rooms are oriented 9° east of due south with some outside obstructions to the east. The window function is separated into a full width clerestory window ("daylight window") above a view window. The window sill height is 0.85 m above the interior floor level.

<table>
<thead>
<tr>
<th>Test room: NTNU</th>
<th>Length</th>
<th>Width</th>
<th>Height</th>
<th>Window area</th>
<th>Glazed area</th>
<th>Occupied</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geometry</td>
<td>5.90 m</td>
<td>2.90 m</td>
<td>2.70 m</td>
<td>4.30 m²</td>
<td>3.20 m²</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Material Photometric Properties

The rooms are furnished with light-coloured surfaces (walls - white, floor - blue grey, ceiling - white). There are some differences in the furnishing of each room.
<table>
<thead>
<tr>
<th>Test room: NTNU</th>
<th>Reflectance</th>
<th>Transmittance of glazing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Walls</td>
<td>Floor</td>
</tr>
<tr>
<td>Surfaces</td>
<td>69 %</td>
<td>18 %</td>
</tr>
</tbody>
</table>

Note: $\tau_{\text{diff}}$ = transmittance for hemispherical irradiation;  
$\tau_{\perp}$ = transmittance for normal irradiation;  
U-value in W/m²K.  
NA = Not available.

**Figure 8-4.9:**  
The south facade of the Norwegian test rooms, located on the top floor. Daylighting systems were installed in the upper horizontal windows.

**Figure 8-4.10:**  
View to the outside in the test room with laser-cut panels (sunny day). A centerline aluminium section is used for location of measurement points.
Equipment for Measurement
All sensors used for interior and exterior illuminance measurements were light-sensitive silicon diodes (PRC Krochmann in Germany). The illuminance levels on the horizontal working plane were measured in the centre line perpendicular to the window at a work plane height of 0.8 m. In addition, a detector was mounted vertically on the rear wall at a height of 1.2 m above the internal floor. All sensors were connected to a data acquisition system (HP 34970A). Exterior sky measurements included global horizontal and one unshielded vertical detector for each orientation.

8.4.4. Lawrence Berkeley National Laboratory (LBNL), USA
Two side-by-side test rooms were used to conduct experimental evaluations of daylighting. The test rooms are located on the fifth floor of an existing high-rise building, located in downtown Oakland, California (latitude 37.1°N, longitude 122.4°W).

Geometry
The test rooms were designed with proportions typical of U.S. private offices. The south-east-facing windows are oriented 62.6° east of due south and have partially obstructed views of nearby high-rise buildings. The windows span the full width of each room, with a sill height of 0.78 m and a head height of 2.58 m.

<table>
<thead>
<tr>
<th>Test room: LBNL</th>
<th>Length</th>
<th>Width</th>
<th>Height</th>
<th>Window area</th>
<th>Glazed area</th>
<th>Occupied</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geometry</td>
<td>4.57 m</td>
<td>3.70 m</td>
<td>2.58 m</td>
<td>8.50 m²</td>
<td>7.52 m²</td>
<td>No</td>
</tr>
</tbody>
</table>
Material Photometric Properties

The rooms are furnished with light-coloured surfaces (walls - white, floor - beige, ceiling - white). In each room, there is a large desk against one sidewall, a credenza against the window, and a bookcase against the opposite sidewall, all of dark-colored wood.

<table>
<thead>
<tr>
<th>Test room: LBNL</th>
<th>Reflectance</th>
<th>Transmittance of glazing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surfaces</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Walls</td>
<td>Floor</td>
</tr>
<tr>
<td></td>
<td>88 %</td>
<td>17 %</td>
</tr>
</tbody>
</table>

Note:  
$\tau_{\text{diff}}$ = transmittance for hemispherical irradiation;  
$\tau_{\perp}$ = transmittance for normal irradiation;  
U-value in W/m²K.

Equipment for Measurement

Interior and exterior illuminance were monitored using Li-Cor cosine corrected sensors. Ten work plane illuminance sensors were located in a 2x5 grid in each test room (height of 0.77 m) and monitored by National Instruments’ LabView data acquisition software. Exterior global and diffuse horizontal illuminance, global horizontal irradiance, and outdoor temperature data were monitored on the roof of an adjacent 5-storey building wing using a Campbell Scientific CR10 data logger.

8.4.5. Bartenbach LichtLabor (BAL), Austria

The experimental assessment of daylight systems was carried out in two furnished mock-up offices at the Bartenbach LichtLabor (BAL). BAL is located southeast of Innsbruck, Austria (latitude 47°N, longitude 11°E).

Geometry

The mock-up offices at BAL consist of two rooms with identical area. The test rooms are orientated to south with high mountains in front. The average angle of obstruction is ~14°, with the highest mountain peak at ~18°. The mountains will reduce the sunny conditions during wintertime, especially at midday. Each room has full-height windows from the sill (0.85 m above floor level) up to the ceiling.
Material Photometric Properties

The rooms are unfurnished with light-coloured surfaces (walls - white, floor - beige, ceiling - white).

<table>
<thead>
<tr>
<th>Test room: BAL</th>
<th>Length</th>
<th>Width</th>
<th>Height</th>
<th>Window area</th>
<th>Glazed area</th>
<th>Occupied</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geometry</td>
<td>5.00 m</td>
<td>2.30 m</td>
<td>2.80 m</td>
<td>4.50 m²</td>
<td>4.50 m²</td>
<td>No</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Test room: BAL</th>
<th>Reflectance</th>
<th>Transmittance of glazing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Walls</td>
<td>Floor</td>
</tr>
<tr>
<td>Surfaces</td>
<td>80 %</td>
<td>30 %</td>
</tr>
</tbody>
</table>

Note:

\( \tau_{\text{dif}} \) = transmittance for hemispherical irradiation;
\( \tau_{\perp} \) = transmittance for normal irradiation;
U-value in W/m²K.
Equipment for Measurement

All sensors used for interior and exterior illuminance measurements were illuminance meter heads from LMT, Germany. Interior horizontal illuminance levels were measured in the centre line perpendicular to the window (5 sensors) at a work plane height of 0.85 m. All sensors were connected to a data acquisition system (Keithley Scanner and LMT Photometer) and the data acquisition software was developed by BAR. Exterior measurements included global horizontal, vertical sky, and vertical ground (south) illuminance.
8.4.6. Queensland University of Technology (QUT), Australia

The experimental assessment of daylight systems was carried out in two unfurnished mock-up offices. QUT is located in Brisbane, Australia (latitude 28°S, longitude 153°E).

Geometry

The mock-up office at the test site consists of one building. The long axis of the test building is oriented 0° due north. There are minor outside obstructions not exceeding 5° in elevation. The building has a single glazed window (1.2 m x 1.2 m) with sill height 0.9 m in the northern end of the building. The building also has two skylight apertures (0.8 m x 0.8 m) in the roof for the comparison of skylight performance. For this skylight comparison, the building (8 m x 3 m x 3 m) can be divided into two rooms (4 m x 3 m x 3 m) by use of a temporary internal wall. Currently the window in the north end of the building is being increased in size to a window 1.6 m high and 2.4 m wide with sill height 0.9 m. The depth of the building from the window was made large (8 m), as the main thrust of daylighting research at QUT is towards improving the natural lighting within deep plan commercial buildings.

![Figure 8.4.17: Elevations of the test room](image)

<table>
<thead>
<tr>
<th>Test room: QUT</th>
<th>Length</th>
<th>Width</th>
<th>Height</th>
<th>Window area</th>
<th>Glazed area</th>
<th>Occupied</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geometry</td>
<td>8.00 m</td>
<td>3.00 m</td>
<td>3.00 m</td>
<td>1.20 m²</td>
<td>1.20 m²</td>
<td>No</td>
</tr>
</tbody>
</table>

Material Photometric Properties

The rooms are unfurnished with light-coloured surfaces (walls - cream, floor - beige, ceiling - white).
<table>
<thead>
<tr>
<th>Surfaces</th>
<th>Reflectance</th>
<th>Transmittance of glazing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Walls</td>
<td>Floor</td>
</tr>
<tr>
<td></td>
<td>60 %</td>
<td>30 %</td>
</tr>
</tbody>
</table>

**Note:**
- $\tau_{\text{diff}}$ = transmittance for hemispherical irradiation;
- $\tau_{\perp}$ = transmittance for normal irradiation;
- U-value in W/m²K.

**Figure 8-4.18:** Exterior view of the test room at QUT with a light-guiding shade

**Figure 8-4.19:** Interior view of test room with light-guiding shade
Equipment for Measurement
Exterior irradiance was measured with two Middleton continuously recording pyrometers (one global and one diffuse). Internal illuminance was measured with cosine and spectrally corrected silicon diode detectors (8) linked to a 16-bit data acquisition system (Picolog). Calibrations were made with a Topcon IM5 photometer. Interior irradiance measurements were made with a Kipp and Zonen irradiance meter. Temperature measurements were usually made with miniature data loggers (Hobo) at suitable positions. The equipment is powered by a photovoltaic/battery power supply providing 240 V AC at about 1 amp.

8.4.7. École Polytechnique Fédérale de Lausanne (EPFL), Switzerland
The experimental assessment of daylight systems was carried out in two mock-up offices at the site of EPFL, located near Lausanne, Switzerland (latitude 46.5°N, longitude 6.6°E).

Geometry
The mock-up offices consist of two rooms with identical dimensions. The test rooms are movable and can be oriented in any direction. The angular altitude of external obstructions is lower than 5°. Each room has windows on the upper part of the facade, the lower part of the wall being opaque (sill height is 1.05 m above the interior floor); the overall facade can be fully glazed if necessary.
Material Photometric Properties

The rooms are furnished with neutral-coloured desks; walls, ceiling and floor surfaces are white to medium grey.

<table>
<thead>
<tr>
<th>Test room: EPFL</th>
<th>Length</th>
<th>Width</th>
<th>Height</th>
<th>Window area</th>
<th>Glazed area</th>
<th>Occupied</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geometry</td>
<td>6.50 m</td>
<td>3.05 m</td>
<td>3.05 m</td>
<td>9.30 m²</td>
<td>4.90 m²</td>
<td>No</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Test room: EPFL</th>
<th>Reflectance</th>
<th>Transmittance of glazing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Walls</td>
<td>Floor</td>
</tr>
<tr>
<td>Surfaces</td>
<td>81 %</td>
<td>16 %</td>
</tr>
</tbody>
</table>

Note: $\tau_{\text{diff}}$ = transmittance for hemispherical irradiation; $\tau_\perp$ = transmittance for normal irradiation; U-value in W/m²K.

Figure 8-4.21:
External view of the two test rooms
Equipment for Measurement

Sensors used for interior illuminance measurements were two rows of 10 calibrated sensors BEHA 96408. Exterior illuminance data were collected by sensors mounted on black honeycomb stitch support (one horizontal LMT/BAP30 FCT, 4 vertical Hagner ELV641, plus one vertical sensor on each facade). All sensors were connected to a Campbell CR10 data acquisition system.

8.4.8. Institut für Lichtund Bautechnik (ILB), Germany

Test Room Description

The experimental assessment of daylight systems was carried out in two unfurnished and unoccupied mock-up offices at the Institute for Light and Building Technique at the University of Applied Sciences Cologne (ILB), Germany. ILB is located in the centre of Cologne (latitude 51°N, longitude 7°E). The test rooms are situated on the roof of the university on the 9th floor.

Geometry

The mock-up offices at ILB consist of 2 rooms with identical geometric measures. The test rooms face due south with few obstructions. Each room has windows in full height, but the lower part of the windows were covered during the measurements (sill height is 0.78 m above the interior floor level). The angle of obstruction was 0° during the measurement period.
Material photometric properties
The rooms are unfurnished with light-coloured surfaces (walls - white, floor - grey, ceiling - white).

<table>
<thead>
<tr>
<th>Test room: ILB</th>
<th>Length</th>
<th>Width</th>
<th>Height</th>
<th>Window area</th>
<th>Glazed area</th>
<th>Occupied</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geometry</td>
<td>6.00 m</td>
<td>3.00 m</td>
<td>2.50 m</td>
<td>9.00 m²</td>
<td>9.00 m²</td>
<td>No</td>
</tr>
</tbody>
</table>

Note:
\[ \tau_{\text{diff}} \] = transmittance for hemispherical irradiation;
\[ \tau_{\perp} \] = transmittance for normal irradiation;
U-value in W/m²K.
Equipment for Measurement

All sensors used for interior and exterior illuminance measurements were light-sensitive silicon diodes with $V(\lambda)$ calibration from PRC Krochmann, Germany. Interior illuminance levels were measured in a centre line perpendicular to the window (6 sensors) at a work plane height of 0.85 m. All sensors were connected to a PC-card-based self-developed data acquisition system. Exterior measurements included global horizontal and shielded vertical sky (south) illuminance.
8.4.9. Building Research Establishment (BRE), UK

Test Room Description
The experimental assessment of daylight systems was carried out in two unfurnished mock-up offices at the Building Research Establishment (BRE). BRE is located in Garston, near Watford, around 30 km north of London (latitude 51.7°N, longitude 0.4°W).

Geometry
The mock-up offices at BRE consist of 2 rooms of identical area. The test rooms are oriented around 10° west of due south. Each room has two windows (window head height is 2.6 m and sill-height is 1 m above the interior floor level) and the windows are almost the full room width, but have extensive glazing bars including a large central pillar. There is a tree to the east of the rooms, which shades the reference room window before 10:30 AM.

Material Photometric Properties
The rooms are unfurnished with light-coloured surfaces (walls - magnolia, floor - dark brown, ceiling - white).

<table>
<thead>
<tr>
<th>Test room: BRE</th>
<th>Length</th>
<th>Width</th>
<th>Height</th>
<th>Window area</th>
<th>Glazed area</th>
<th>Occupied</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geometry</td>
<td>9.00 m</td>
<td>3.00 m</td>
<td>2.70 m</td>
<td>4.80 m²</td>
<td>3.60 m²</td>
<td>No</td>
</tr>
</tbody>
</table>

Material Properties

<table>
<thead>
<tr>
<th>Test room: BRE</th>
<th>Reflectance</th>
<th>Transmittance of glazing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surfaces</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Walls</td>
<td>80 %</td>
<td>85 %</td>
</tr>
<tr>
<td>Floor</td>
<td>9 %</td>
<td>95 %</td>
</tr>
<tr>
<td>Ceiling</td>
<td>80 %</td>
<td></td>
</tr>
<tr>
<td>U-value</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: $\tau_{\text{dif}} =$transmittance for hemispherical irradiation;
$\tau_{\perp} =$ transmittance for normal irradiation;
U-value in $\text{W/m}^2\text{K}$.
Equipment for Measurement

All sensors used for interior illuminance measurements were light-sensitive selenium diodes from Megatron, London, UK. Except for the direct normal illuminance, exterior illuminance sensors were silicon diodes supplied by LMT Lichtmesstechnik Berlin. The direct normal sensor was a Li-Cor silicon photocell mounted in an Eppley normal incidence pyrheliometer. Interior illuminance levels on the horizontal were measured in the centre line perpendicular to the window (6 sensors) at a work plane height of 0.7 m. All sensors were connected to a data acquisition system (using a Keithley A/D converter) and the data acquisition software was developed by Cambridge Consultants under contract to BRE. Exterior measurements included global horizontal, diffuse horizontal (using a shade ring),
direct solar normal (using a solar tracker), and vertical total illuminance in the plane of the test room window. This was shielded from the ground-reflected light by a black honeycomb material.

8.4.10. Summary of Monitoring and Data Acquisition Systems

Description of Monitoring Equipment for Measurement

<table>
<thead>
<tr>
<th>Institute</th>
<th>Manufacturer</th>
<th>Range (klux)</th>
<th>Calibration</th>
<th>Maximum calibration error</th>
<th>V(A) (l')</th>
<th>Cosine response error (l)</th>
<th>Fatigue error (f)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia (QUT)</td>
<td>TopCon IMS LMT</td>
<td>0.1 - 200</td>
<td>1998</td>
<td>± 2%</td>
<td>± 2%</td>
<td>± 2%</td>
<td>± 5%</td>
</tr>
<tr>
<td>Austria (BAL)</td>
<td></td>
<td></td>
<td>1994-1998</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Denmark (SBI)</td>
<td>Hagner</td>
<td>0.1 - 100</td>
<td>1993/1998</td>
<td>&lt; 3%</td>
<td>&lt; 3%</td>
<td>&lt; 3%</td>
<td></td>
</tr>
<tr>
<td>Germany (ILB)</td>
<td>ILB</td>
<td>1.0 - 120</td>
<td>1996</td>
<td>± 10 lux</td>
<td>&lt; 3%</td>
<td>&lt; 0.4%</td>
<td></td>
</tr>
<tr>
<td>Germany (TUB)</td>
<td>LMT</td>
<td>0.1 - 100</td>
<td>1996</td>
<td>± 0.6%</td>
<td>&lt; 3%</td>
<td>&lt; 2%</td>
<td></td>
</tr>
<tr>
<td>Norway (NTNU)</td>
<td>PRC Krohnmann</td>
<td>50 - 200</td>
<td>1996</td>
<td>0.5%</td>
<td>&lt; 2%</td>
<td>&lt; 1%</td>
<td>&lt; 0.1%</td>
</tr>
<tr>
<td>Switzerland (LESO)</td>
<td>BEHA</td>
<td>1.0 - 100</td>
<td>1996</td>
<td>2.5%</td>
<td>3%</td>
<td>2%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>L.M.T.</td>
<td>1.0 - 100</td>
<td></td>
<td></td>
<td>3%</td>
<td>2%</td>
<td></td>
</tr>
<tr>
<td>United Kingdom (BRE)</td>
<td>Megatron</td>
<td>0.01-7.5/50</td>
<td>12 month interval</td>
<td>3%</td>
<td>0.5%</td>
<td>3%</td>
<td>1%</td>
</tr>
<tr>
<td>USA (LBNL)</td>
<td>Li-Cor</td>
<td>0.0 - 150</td>
<td>1995</td>
<td>1%</td>
<td>-</td>
<td>1%</td>
<td>-</td>
</tr>
</tbody>
</table>

Description of Data Acquisition System

<table>
<thead>
<tr>
<th>Institute</th>
<th>Manufacturer</th>
<th>Type</th>
<th>No. of differential analogue input channels</th>
<th>A/D converter resolution (in bits)</th>
<th>Data acquisition software</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia (QUT)</td>
<td>Pico Log LMT, Keithley</td>
<td>PC Board Scanner + Photometer</td>
<td>8</td>
<td>16</td>
<td>Pico Log BLL</td>
</tr>
<tr>
<td>Austria (BAL)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Denmark (SBI)</td>
<td>Keithley SmartLink KNM - DVC-32</td>
<td>Datalogger</td>
<td>80</td>
<td>20</td>
<td>SBI</td>
</tr>
<tr>
<td>Germany (ILB)</td>
<td>ILB</td>
<td>PC Board</td>
<td>16</td>
<td>14</td>
<td>ILB</td>
</tr>
<tr>
<td>Germany (TUB)</td>
<td>Delfin Instr. / Keithley</td>
<td>PC Board</td>
<td>20</td>
<td>21</td>
<td>TUB</td>
</tr>
<tr>
<td>Norway (NTNU)</td>
<td>National Instruments</td>
<td>PC Board</td>
<td>16</td>
<td>12</td>
<td>LabView</td>
</tr>
<tr>
<td>Switzerland (LESO)</td>
<td>Campbell</td>
<td>Datalogger</td>
<td>32</td>
<td>12</td>
<td>PC 208 W</td>
</tr>
<tr>
<td>UK (BRE)</td>
<td>Keithley</td>
<td>PC Board</td>
<td>32</td>
<td>12</td>
<td>Cambridge consultants</td>
</tr>
<tr>
<td>USA (LBNL)</td>
<td>Campbell Scientific (CR10) and LabView</td>
<td>Datalogger/PC Board</td>
<td>25 (+3)</td>
<td>12</td>
<td>LabView National Instruments</td>
</tr>
</tbody>
</table>
8.5. Monitoring Procedures

IEA Task 21 Monitoring Procedures for Assessing the Daylighting Performance of Buildings

Monitoring of daylighting systems and daylight-responsive lighting control systems was carried out in test rooms in Australia, Austria, Denmark, Finland, France, England, Germany, the Netherlands, Norway, Switzerland, and the United States. A Monitoring Protocol, including monitoring procedures, was formulated for these studies; this protocol focuses on quantifying the performance of the systems evaluated. This appendix summarises the information that can be found in the IEA SHC Task 21 document “Monitoring Protocol” (appended to the CD-ROM of this book).

8.5.1. Objectives of the Monitoring Procedures

The objective of the monitoring procedures is to establish a basis for evaluating a daylighting or lighting control strategy compared to a reference situation in occupied and unoccupied rooms under real sky conditions. These procedures describe the parameters to be considered, and give guidance for measurements as well as procedures for user assessment. Different levels of monitoring are included. The monitoring level selected depends on the capacities of a test situation, i.e., available measurement equipment, and the daylighting system or control strategy to be tested. The Monitoring Protocol also includes recommendations for documentation of testing procedures and evaluation of the system’s performance compared to a reference situation. This protocol can be used for studies in standard offices with only vertical window(s) and horizontal work planes.

8.5.2. Approach

Daylighting systems are used to redirect incoming sunlight or skylight to areas where it is required. Therefore, these systems need to be evaluated for their ability to control daylight levels and to redirect sunlight and skylight into the perimeter zone of a building under overcast and clear sky situations. Because a traditional window will often provide non-uniform daylight distribution, daylighting systems should also be evaluated for their ability to reduce the large variations in the daylight levels within a room.

Daylight-responsive artificial lighting control systems are generally designed to maintain an illuminance level set in the tuning procedure. By supplementing daylight when it is insufficient, these systems save energy. Therefore, illuminance levels on the work plane and lighting energy consumption both need to be monitored.

The overall performance of a daylighting or control system is determined by the capability of the system to meet the requirements mentioned above while maintaining visual quality.
in a room. Therefore, visual comfort and other related parameters are included in the monitoring procedures to assess user acceptance of the room illumination and the installed system(s). A system's capability is assessed by comparing a room where the system is installed to an identical reference room without the system, under the same sky conditions. Daylighting conditions in the two rooms and exterior conditions are monitored simultaneously.

The reference room for testing a daylighting system under overcast skies has a double pane of clear glazing. For clear sky measurements, a shading system that is typical for the region should be included, e.g., downward-tilted venetian blinds. No artificial lighting is used.

The reference room for testing a daylight-responsive artificial lighting control system is equipped with existing luminaires that do not have the control system.

8.5.3. Monitoring Procedures
The monitoring procedures have four phases:

- A decision phase, in which choices are made regarding testing and the types of measurements to be carried out;
- A preparatory phase, in which the unchangeable conditions of the test rooms and monitoring equipment to be used are recorded in a descriptive document;
- A monitoring programme, which includes procedures for systematically verifying conditions and sensors; and
A conclusion phase, in which the performance of the daylighting systems or daylight-responsive artificial lighting control system is determined based on the test results.

Minimum Measurements
Exterior measurements that will provide the minimum basis for evaluating a selected daylighting system include the horizontal global illuminance and the vertical sky illuminance. Interior work plane measurements should include those which enable one to check the system’s ability to increase daylight penetration, provide “uniform” illuminance distribution, or maintain a certain illuminance level in the room (see, for example Figure 8-5.2). The height of the horizontal work plane should be consistent with the standard in the country where testing is performed (0.70–0.85 m above floor level).

The location of sensors depends on the number of sensors available and the monitoring level (minimal or with additional requirements). For monitoring a daylighting system, the locations will also depend on the daylighting system used. When a daylight-responsive artificial lighting control system is used, sensor locations depend on window size and transmittance.

Visual Comfort and User Acceptance
At a minimum, evaluation of visual comfort and user acceptance in a test room situation consists of observations in the occupied and unoccupied rooms. It includes the detection of sun patches areas with high luminance and glare.

For a more extensive evaluation of visual comfort and user acceptance, a standard questionnaire has been developed (see CD-ROM for more detailed monitoring procedures). When daylighting systems are tested, the questionnaire should include questions on glare (direct and indirect), illuminance distribution, illuminance levels at the work plane, and
questions concerning satisfaction and acceptance of the system. When control systems are tested, the questionnaire should include questions on illuminance distribution, maintained illuminance level on the work plane, and questions related to the system.

**Duration of Monitoring in Unoccupied Test Rooms**

The time period for a minimum evaluation of a daylighting system or a control system is: One day under overcast sky conditions and three days (winter and summer solstices and equinox) when the sky is clear.

For overcast sky with ideal CIE sky luminance distribution, one measurement may be sufficient. However, it is recommended that a full day of measurements be carried out.

Measurements under clear sky conditions should be taken within eight weeks around the winter and summer solstices and the equinox.

Long-term monitoring is preferable for daylight-responsive artificial lighting control systems, to establish realistic energy saving potentials.

**Additional Measurements For a More Detailed Evaluation**

Additional measurements are suggested to monitor system-specific characteristics. Many daylighting systems are used to redirect daylight. Luminance and illuminance measurements on walls and ceiling can be used to monitor this ability. Monitoring can also include supplementary measurements to evaluate a daylighting system’s capability to reduce discomfort glare.

**Analysis of the Results**

The performance of a daylighting system should be presented in comparison to the reference situation. Advantages and disadvantages can be assessed by comparison of absolute illuminance levels, daylight factors, and daylight distribution. Overall performance of a system should include assessment of user acceptance of the system.

The performance of daylight-responsive artificial lighting control systems can be expressed in terms of their capability to control artificial light in response to available daylight, to maintain the design illuminance level, and to reduce energy consumption. In addition, monitoring results should show duration, frequency, and magnitude of insufficient light levels. The overall performance of these systems should include an evaluation of user acceptance.

**8.5.4. Conclusion**

Until now, no standard monitoring procedures have been available for assessing and comparing performances of daylighting systems and daylight-responsive lighting control systems. The lack of monitoring protocols has been rectified by this documentation of the
performance assessment of selected systems using standard monitoring methods in test rooms under real sky conditions.

The emphasis in the monitoring procedures used in the evaluation of daylighting and daylight-responsive control systems in IEA SHC Task 21 was on effective daylight utilisation, electrical energy savings, and user acceptance. These monitoring procedures have been proven to be effective; therefore they are a valuable method for future evaluations to determine system performance. The complete monitoring procedures are included in the CD-ROM appended to this book.
Prismatic Elements

3M (Scotch Optical Lighting Film)
3M Center Bldg. 225-2N06
St. Paul, MN 55144-1000
United States
Tel. +1 (612) 733-1898
Fax +1 (612) 736-3893
Prismatic film, light pipes, mirror film

Siteco (formerly Siemens)
Beleuchtungsstarke GmbH
Ohmstrasse 50
83301 Traunreut
Germany
Tel. +49 8669 331
Fax +49 8669 33684
Prismatic glazing, mirrored louvers, eggcrate microlouver, reflective ceilings

Yazaki Co. Ltd.
1370 Koyasu-cho
Hamamatsu-shi
Shizuoka 435
Japan
Tel. +81 534-61-7111
Prismatic glazing

Bartenbach Lichtlabor
Rinner Str. 14
6071 Aldrans/Innsbruck
Austria
Tel. +43 512 386810
Fax +43 512 378048
Prismatic panels, louver and blinds, light shelves

Redbus Serraglaze
3 The Quadrant
Coventry CV1 2DY
United Kingdom
Tel. +44 1203 243621
Fax +44 1203 243622
Stacked reflector/refractor array prismatic sheet
Holographic Optical Elements

Institut fur Licht-und Bautechnik an der Fachhochschule Köln
Gremberger Straße 151a
50679 Köln
Germany
Tel. +49 221 831096
Fax +49 221 835513
Holographic glazing, transparent shading systems, light-guiding glass

Advanced Environmental Research Group
3681 S Lagoon View Drive
Greenbank, WA 98253
United States
Tel. +1 (206) 678 5439
Fax +1 (206) 678 5439
Holographic glazing

Autotype Limited
Grove Road
Wantage Oxfordshire
OX12 9BZ
United Kingdom
Tel. +44 1235 767777
Fax +44 1235 771196
Holographic glazing

Seele GmbH & Co KG
Gutenbergstraße 19
86368 Gersthofen
Germany
Tel. +49 821 2494 0
Fax +49 821 2494 100
Transparent shading

Louvers and Blinds

Altasol Ltd.
18 Gilmour Street
Burwood, Victoria 3125
Australia
Reflective louvres

Okalux Kapillarglas GmbH
Am Jöpershecklein
97828 Marktheidenfeld-Altfeld
Germany
Tel. +49 93 91 10 41
Fax +49 93 91 68 14

Colt International Limited
New Lane
Havant, Hampshire PO9 2LY
United Kingdom
Tel. +44 1705 451111
Fax +44 1705 454220
Moveable louvers

Hallmark Blinds Ltd
173 Caledonian Road
Barnsbury
London N1 0SL
United Kingdom
Tel +44 207 837 0964/8181
Fax +44 207 833 1693

SEA Corporation
2010 Fortune Drive, Suite 102
San Jose, CA 95131,
United States
Tel. +1 (408) 954-1250
Fax +1 (408) 954-1254

Synertech Systems Corporation
472 South Salina St. Suite 800
Syracuse, NY 13202
United States
Tel. +1 (315) 422-3828
Daylight microlouvers
Hunter Douglas Limited
Mersey Industrial Estate
Heaton Mersey, Stockport
Cheshire SK4 3EQ
United Kingdom
Tel. +44 161 432 5303
Fax +44 161 431 5087
Reflective blinds

WAREMA Renkhoff GmbH
Vorderbergstraße 30
97828 Marktheidenfeld
Germany
Tel. +49 9391 20600
Fax +49 9391 20279

F Muller Pty Ltd.
16 St Albans Road
Kingsgrove, NSW 2208
Australia
Tel. +61 5022633

GlasTec
Rosenheimer Glastechnik GmbH
Neue Straße 9
Stephanskirchen
Germany
Tel. +49 8031 73145
Fax +49 8031 73243

Baumann-Hüppe AG
Zugerstrasse 162
Postfach 100
8820 Wädenswyl
Switzerland
Tel. +41 1 782 5111
Fax +41 1 782 5204

Huppe Form GmbH
Sonnenschutz und Raumsysteme
Postfach 25236015 Oldenburg
Germany
Tel. +49 441 402282
Fax +49 441 402 454
Reflective blinds

Glas Schuler GmbH & Co.KG
Ziegelstraße 23-25
91126 Rednitzhembach
Germany
Tel. +49 9122 / 7046
Fax +49 9122 70515

Dasolas Internat.
Productions
A/S Moegelgaardsvej 9-13
8529 Lystrup
Denmark

Brüder Eckelt + Co
Glastechnikgesellschaft mbH
Resthofstr. 18
4400
Austria
Tel.: +43 (7252) 894-0
Fax +43 (7252) 894-24
Heliostats

Bomin Solar
Industriestrasse 8-10
79541 Lörrach
Germany
Tel. +49 7621 95960
Fax +49 7621 54368
Heliostats, mirrors, prisms, lenses

La Forêt Engineering & Information Service Co. Ltd.,
Himawari Building,
Toranomon 2-7-8
Minato-ku, Tokyo 105, Japan
Tel. +81 3 3593 0091
Fax +81 3 3593 0095
Himawari (heliostat and fibre optic)

Sumitomo Corporation
444 South Flower St.
Los Angeles, CA 90071-2975
United States
Tel. +1 (213) 489-0371
Fax +1 (213) 489-0300
Himawari (heliostats and fibre optics)

EGIS GmbH
Flutstr. 34-36
63071 Offenbach/Main
Germany
Tel. +49 (69) 85 83 27
Fax +49 (69) 85 78 63

Light Pipes

The Sun Pipe Company
PO Box 2223
Northbrook, IL 60065
United States
Tel. +1 (800) 8444786
Fax +1 (708) 272 6972
Light pipes

Alternate Energy Institute
5335 Mission Center Rd. No. 351
San Diego, CA 92108
United States
Tel. +1 (619) 692-2015
Heliostats

Solartech
A. Kuzelka
Heugasse 8/1
2344 Maria Enzersdorf
Austria
Tel. 0664 481 14 12
Double mirror heliostat

Zentrum für Sonnenenergie- und Wasserstofforschung
Hessbruhelstrasse 2lc
70565 Stuttgart
Germany
Tel. +49 (711) 7870 222
Thermohydraulic heliostat

Schlaich Bergermann & Partner
Stuttgart
Germany
Tel. +49 711 64 87 10

Solartube Ltd.
5825 Avenida Enchinas, Suite 101
Carlsbad, CA 92008
United States
Tel. +1 (619) 929 6060
Light pipes
Monodraught Limited
6 Lancaster Court
Cressex Business Park
High Wycombe, Bucks HP12 3TD
United Kingdom
Tel. +44 1494 464858
Fax +44 1494 532465
Light pipes

Sanyo Electric Co. Ltd.
Air Conditioning and Refrigeration Development Center
180 Sakata Oizumi-machi, Ora-gun
Gunma, Japan
Tel. +81 (276) 618122
Fax +81 (276) 618802
Double prism heliostats, light pipes

Skydome Ltd.
Unit 21
Springtown Industrial Estate
Springtown, Londonderry BT 46 OLY
United Kingdom
Tel. +44 1504 370270
Fax +44 1504 373411
Corrugated light pipe systems

Laser-Cut Panels

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Queensland University of Technology
GPO Box 2434
Brisbane Q 4001
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Tel. +61 7 864 2329
Fax +61 7 864 1521
Laser-cut light deflecting sheets, stacked curved daylight deflecting prisms

LTI Lichttechnik
Heiko Schnetz GmbH
Konrad-Adenauer-Str. 25
50996 Köln
Germany
Tel. +49 221 35099 70
Fax +49 221 35099 71

LGM & Associates
PO Box 2613
Northbrook, IL 60062
United States
Tel. +1 (708) 272-6977
Light pipes

INGLAS - Innovative Glassysteme GmbH & Co. KG
Im Winkel 4/1
88048 Friedrichshafen
Germany
Tel. +49 7544 6547 - 23
Special glazings
Skydome Skylight Systems Ltd
39 Antimony Street
Carole Park QLD 4300
PO Box 154 Goodna QLD 43400
Australia
Tel. 61 7 3271 3200
Fax 61 7 3271 4481
Angular selective skylights

Synergetics Inc.
122 Cox Avenue
Raleigh, NC 27605
United States
Tel. +1 (919) 832 4011
Variable area light reflecting assembly

Anidolic Systems

Solar Energy and Building Physics
Laboratory (LESO-PB)
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Anidolic systems

Felix Constructions SA
Route de Renens 1
1030 Bussigny-Lausanne
Switzerland
Tel. +41 21 701 0441
Fax +41 21 701 31 68
Facade integrated Anidolic systems