Appendices 8.

Glossary 8.1.

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 / cm^2.

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/m^2) of any point in the sky at an angle of elevation γ above the horizon, is assumed to be given by the relation:

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

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:

$$(L_1 – L_2) / L_1$$

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.

References and Bibliography 8.2.

Chapter 1.: Introduction

Boyce, P. 1998. "Why Daylight?" *Proceedings of Daylight '98, International Conference on Daylighting Technologies for Energy Efficiency in Buildings*, Ottawa, Ontario, Canada: 359-365.

Chapter 2.: Daylight in Building Design

Baker, N. and K. Steemers. *2000. Energy and Environment in Architecture;* A Technical Design Guide. London.

Dumortier, D. *1995. Mesure, Analyse et Modélisation du gisement lumineux*; Application à l'évaluation des performance de l'éclairage naturel des bâtiments. Vaulx-en-Velin.

Fontoynont, M. (editor) *1999. Daylight performance of buildings*. London: James and James.

IEA SHC Task 21 *Daylight in Buildings: 15 Case Studies from Around the World*. See http://www.iea-shc.org.

Littlefair, P. *1991. Site layout planning for daylight and sunlight: a guide to good practice. British Research Establishment (BRE) Report*, Garston, UK. LUMEN 1995.

LUMEN. *1995. LUMEN, Étude Typologique; Programme interdisciplinaire: LUMEN, ANNEXE B, Fiches Modèles*. École Polytechnique de Lausanne.

O'Connor, J., E.S. Lee, F.M. Rubinstein, S.E. Selkowitz. *1997. Tips for daylighting with windows: the integrated approach. PUB 790*, Ernest Orlando Lawrence Berkeley National Laboratory, Berkeley.

Robbins, C.L. *1986. Daylighting: Design and Analysis*. New York:Van Nostrand Reinhold Company.

Chapter 3.: Performance Parameters

Aydinli, S. and M. Seidl. *1986. Determination of the economic benefits of daylight in interiors concerned with the fulfillment of visual tasks.* M.S. Adepski and R. McCluney (Editors), Proceedings I: 1986 International Daylighting Conference, 4-7 November 1986, Long Beach, California, USA: 145-151.

Baron, R.A., Rea, M.S., Daniels, S.G. *1992. Effects of indoor lighting (illuminance and spectral distribution) on the performance of cognitive tasks and interpersonal behaviors: The potential mediating role of positive affect*. Motivation and Emotion (16): 1-33.

CIE-29.2. *1986. Guide on interior lighting. Vienna, Austria*: Bureau Centrale de la Commission Internationale de L'Éclairage.

CIE-117. *1995. Discomfort glare in interior lighting. Vienna, Austria*: Bureau Central de la Commission Internationale de L'Éclairage.

Courret, G., Scartezzini, J.L., Francioli, D., Meyer, J.J. *1998. Design and assessment of an anidolic light duct*. Energy and Buildings 28 (1998): 79-99.

Hopkinson, R.G. *1972. Glare from daylighting in buildings. Applied Ergonomics (3)*: 206-215.

Hopkinson, R.G. *1963. Daylight as a cause of glare. Light and Lighting*, November 1963: 322-326.

IES 1993a. *Lighting Handbook: Reference and Application, 8th edition*. Illuminating Engineering Society of North America, New York, New York.

IES 1993b. *American National Standard Practice for Office Lighting.* ANSI/IESNA RP-1-1993. Illuminating Engineering Society of North America, New York, New York.

Tiller, D.K., Veitch, J.A. *1995. Perceived room brightness: Pilot study on the effect of luminance distribution*. Lighting Research and Technology (27): 93-101.

Chapter 4.: Daylighting Systems

4.3.: Light Shelves

Aizlewood, M.E. *1993. Innovative daylighting systems: An experimental evaluation*. Lighting Research & Technology (14)4.

Beltran, L.O., E.S. Lee, S.E. Selkowitz. *1997. Advanced Optical Daylighting Systems: Light Shelves and Light Pipes*. Journal of the Illuminating Engineering Society 26 (2): 91-106.

Christoffersen, J. *1995. Daylight utilisation in office buildings. Ph.D. Dissertation*, Danish Building Research Institute, Report 258.

Howard, T.C., W. Place, B. Anderson, P. Coutiers. *1986. Variable-area light reflecting assemblies (VALRA). Proceedings of the 2nd International Daylighting Conference*, Long Beach.

Lam, W. *1986. Sunlighting as formgiver for architecture.* New York: Van Nostrand Reinhold Company.

Lee, E.S., L.O. Beltrán, S.E. Selkowitz, H. Lau, G.D. Ander. *1996*. "Demonstration of a light-Redirecting Skylight System at the Palm Springs Chamber of Commerce." *Proceedings from the ACEEE 1996 Summer Study on Energy Efficiency in Buildings, 4:229-241*. Washington, D.C.: American Council for an Energy-Efficient Economy.

Littlefair, P.J. *1995. Computer assessment of the daylighting performance of light shelves*. Lighting Research & Technology (27)2.

Littlefair, P.J. *1996. Designing with innovative daylighting*. Building Research Establishment, Construction Research Communications Ltd Report.

Michel, L. *1998. Scale model-daylighting systems evaluation*. IEA SHC Task 21 Working Document, EPFL.

4.4.: Louvers and Blinds Systems

Inoue, T., T. Kawase, T. Ibamoto, S. Takakusa, Y. Matsuo. *1988. The development of an optimal control system for window shading devices based on investigations in office buildings*. ASHRAE Transactions 94(2).

Pohl, W., Scheiring, C. *1998. Charakterisierung von Tageslichtsystemen, OTTI 1998, Viertes Symposiom Innovative Lichttechnik in Gebäuden*, Tagungsband, pp. 133-140, Staffelstein Jan 1998.

Rea, M.S. 1984. *Window blind occlusion: A pilot study.* Building and Environment (19)2: 133-137.

Rubin A.I., Collins, B.L., Tibbott, R.L. *1978. Window blinds as a potential energy saver – a case study, Building Science series 112 NBS*, Washington National Bureau of Standards.

4.5.: Prismatic Panels

Aizlewood, M.E. *1993. Innovative daylighting systems*: An experimental evaluation. Lighting Research & Technology (14)4.

4.6.: Laser-Cut Panels

Edmonds, I.R. *1993. Performance of laser-cut deflecting panels in daylighting*. Solar Energy Materials and Solar Cells (29): 1-26.

Reppel, J., I.R. Edmonds. *1998. Angle selective glazing for radiant heat control in buildings*: Theory. Solar Energy (62) 245-253.

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

Edmonds, I.R., P.A. Jardine, G. Rutledge. *1996. Daylighting with angular selective skylights: predicted performance*. Lighting Research & Technology (28)3: 22-130.

4.8.: Light-Guiding Shades

Edmonds I.R. *1992. Permanently fixed collimation devices which combine the function of shading and daylighting building interiors*. Australian Patent AU-B-15055/92.

4.9.: Sun-directing Glass

Kischkoweit-Lopin, M. *1996. New Systems for Better Daylight Utilization*, Proceedings of Solar Energy in Architecture and Urban Planning, Berlin, Germany.

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

Kischkoweit-Lopin, M. *1999. Application of new developed daylighting systems in real case studies*, Proceedings of IDC 98 (International Daylighting Conference) in Ottawa, Canada.

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

Müller, H. 1996. *Erprobung elner anpassungsfähigen Fassade für die ganzjährige Solarenergienutzung (Testing of a flexible facade for usage of solar energy through the year), Bauphysik 1/96*, Verlag Ernst & Sohn, Berlin (1996).

4.12.: Anidolic Ceilings

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

Welford, W.T., R. Winston. *1989. Non-imaging optics*. New York: Academic Press.

4.13.: Anidolic Zenithal Openings

Courret G., B. Paule, J.L. Scartezzini. *1996. Anidolic zenithal openings: Daylighting and shading*. Lighting Research and Technology 28(1): 11-17.

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

4.14.: Anidolic Solar Blinds

Courret, G. *1999. Systèmes anidoliques d'éclairage naturel*, Thèse de Doctorat No 2026, DA/EPFL, 1999-12-16.

Chapter 5.: Daylight-Responsive Controls

Andersson, B., M. Adegram, T. Webster, W. Place, R. Kammerud, P. Albrand. *1987. Effects of daylighting options on the energy performance of two existing passive commercial buildings*. Building and Environment 22(1): 3-12.

Christoffersen, J., Johnsen, K., Petersen, E., Hygge, S. *1999. Post-occupancy evaluation of Danish offices, Proceedings*, CIE Conference, Poland, pp. 333-337.

Crisp, V.H.C. *1984. A case for active daylighting by appropriate management of electric lighting*. Energy and Buildings (6): 151-158.

Guillemin, A. and N. Morel. *2001. An Innovative lighting controller integrated in a self-adaptive building control system*. Energy and buildings 33(5): 477-487.

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

Hygge, S. and H.A. Löfberg. *1999. Post occupancy evaluation of daylight in buildings.* A report of IEA Task 21/ Annex 29. Published by KTH - Royal Institute of Technology, Centre for Built Environment, Gavle, Sweden, Staffan.hygge@hig.se.

Jennings, J. D., Rubinstein, F.M., DiBartolomeo, D., Blanc, S. *1999. Comparison of control options in private offices in an advanced lighting controls testbed*. LBNL Report LBNL-43096.

Kittler, R; Hayman, S; Ruck, N.C; Julian, W.G. *1992. Daylight measurement data: Methods of evaluation and representation*. Light. Res. Technol., 24, 173-187.

Kittler, R., Perez, R., Darula, S. *1999. Universal models of reference daylight conditions based on new sky standards*. Proceedings 24th Session of the CIE, pp. 243-248.

Lee, E.S., D.L. DiBartolomeo, S.E. Selkowitz 1998a. "Thermal and Daylighting Performance of an Automated Venetian Blind and Lighting System in a Full-Scale Private Office." Energy and Buildings 29(1)1998: 47-63.

Lee, E.S., D.L. DiBartolomeo, E.L. Vine, S.E. Selkowitz 1998b. "Integrated Performance of an Automated Venetian Blind/Electric Lighting System in a Full-Scale Private Office." *Thermal Performance of the Exterior Envelopes of Buildings VII*: Conference Proceedings, Clearwater Beach, Florida, December 7-11, 1998.

LESO-PB/EPFL 1996. *DELTA, A blind controller using fuzzy logic*, Final Report.

Littlefair, P.J. *1984. Daylight availability for lighting controls. Proc*. CIBS National Lighting Conference, Cambridge.

Littlefair, P.J., Heasman, T.A. *1998. A case study of technology and the user interface: The effectiveness of lighting controls in a range of building types*. Proceedings Intelligent buildings conference, BRE, Garston, 1998.

Littlefair, P.J., Lynes, J.A. *1999. Responding to change. Light and Lighting*, April, 1999.

Love, J.A. *1998. Daylighting control systems: Directions for the future based on lessons from the past*. Proc. Daylighting '98 299-306.

Maniccia, D., Rutledge, B., Rea, M., Morrow, W. *1998. Occupant use of manual lighting controls in private offices.* Proceedings 1998 IESNA Conference, August 1998.

Newsham, G., Mahdavi, A., Beausoleil-Morrison, I. *1995. Lightswitch: a stochastic model for predicting office lighting energy consumption.* Proceedings of Right Light Three: the Third European Conference on Energy Efficient Lighting Vol. 1 - Published Papers 59-66.

Opdal, K., Brekke, B. *1995. Energy savings in lighting by utilisation of daylight. Proceedings of Right Light Three*: the Third European Conference on Energy Efficient Lighting Vol. 1 - Published Papers 67-74.

Rubinstein, F., Siminovitch, M., Verderber, R. *1991. 50% energy savings with automatic lighting controls.* IEEE-IAS Transactions on Industry applications.

Rubinstein, F., Avery, D., Jennings, J., Blanc, S. *1997. On the calibration and commissioning of lighting controls.* Proceedings of 4th Right Light Conference, Copenhagen, November 1997. LBNL Report LBNL-41010.

Rubinstein, F.D., Jennings, J., Avery, D., Blanc, S. *1999. Preliminary results from an advanced lighting controls testbed.* Presented at the IESNA 1998 Annual Conference, San Antonio, TX, August 10-12, 1998, and published in J. of the IES (Winter 1999).

Rubinstein, F., S. Johnson, P. Pettler. *2000. IBECS: an Integrated Building Environment Communications System It's Not Your Father's Network.* Proceedings of the 2000 ACEEE Summer Study on Energy Efficiency in Buildings, August 20-25, 2000, Pacific Grove, CA.

Slater, A.I. Bordass, W.T., Heasman, T.A. *1996. People and lighting controls.* Information paper IP 6/96, Garston: CRC.

Zonneveldt, L., Mallory-Hill, S. *1998. Evaluation of Daylight Responsive Lighting Control Systems, Proc.* 'Daylighting '98,' 223-231.

Chapter 6.: Design Tools

Aizlewood, M.E, P.J. Littlefair. *1996. Daylight prediction methods: A survey of their use. Conference Papers*, CIBSE National Lighting Conference, pp. 126-140, Bath.

Baker, N.V., A. Fanchiotti, K. Steemers (editors). *1993. Daylighting in Architecture.* CEC DG II, James & James, London.

CIBSE. *1987. Window design - Application Manual*, London.

Compagnon, R. *1993. "Simulation numérique de systèmes d'éclairage naturel à pénétration latérale"*, Thèse de Doctorat No 1193, EPFL, Lausanne.

de Boer, J., H. Erhorn. *1998. Survey of simple design tools.* Final document of IEA SHC Task 21.

Erhorn, H., M. Dirksmöller (editors). 2000. Documentation of the Software Package ADELINE 3, Fraunhofer-Institut für Bauphysik, Stuttgart.

Fontoynont, M. et al. 1999. Validation of daylighting simulation programmes within IEA Task 21, Proc. of CIE Conference, Warsaw, 24-30 June 1999.

Hopkinson, R.G., P. Petherbridge, J. Longmore. *1966. Daylighting*. London: William Heinemann Ltd.

Kenny, P., J.O. Lewis (editors). *1995. Tools and Techniques for the Design and Evaluation of Energy Efficient Buildings.* EC DG XVII Thermie Action No B 184, Energy Research Group, University College Dublin.

Lighting Design and Application 1996. "1996 IESNA Lighting Design Software Survey," pp. 39-47, New York, September.

McNicholl, A., J.O. Lewis (editors). *1994. Daylighting in Buildings.* EC DG XVII Thermie, Energy Research Group, University College, Dublin.

Michel, L., C. Roecker, J.L. Scartezzini. *1995. Performance of a new scanning sky simulator.* Lighting Research & Technology 27(4): 197-207.

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

Paule B., R. Compagnon, J.L. Scartezzini. *1995. Toward a new daylighting design computer too*l, Proc. of 3. Conf. on Energy Efficient Lighting, Newcastle-upon-Tyne, UK.

Tregenza, P.R. *1989. Daylight measurement in models: new type of equipment*, Lighting Research and Technology (21)4: 193-194.

Ward, G.J., F.M. Rubinstein. *1988. A new technique for computer simulation of illuminated space*, Journal of the Illuminating Engineering Society 17(1).

8.3.: Optical Characteristics of Daylighting Materials

Apian-Bennewitz, P.; *Designing an apparatus for measuring bi-directional reflection/ transmission*, SPIE vol. 2255, S. 697-706.

Aydinli, S., Kaase, H., Scartezzini, J. L., Michel, L., Kischkoweit-Lopin, M., Wienold, J., Apian-Bennewitz, P.: *1998. Measurement of Photometric Characteristics of Daylighting Systems*, Proc. of International Daylighting Conference, Ottawa, Canada.

CIE Publ. No. 38 (T.C. - 2.3), *Radiometric and photometric characteristics of materials and their measurements*, 1977.

CIE Publ. No. 46 (TC - 2.3), *A review of publications on properties and reflection values of materials reflection standards*, 1979.

CIE Publ. No. 44 (TC - 2.3), *Absolute methods for reflection measurements*, 1979.

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

CIE Publ. No. 15.2, *Colorimetry*, 1986.

CIE Publ. No. 17.4, *International lighting vocabulary*, 1987.

CIE Publ. No. 130 (TC - 2-14), *Practical Methods for the Measurement of Reflectance and Transmittance*, 1989.
CIE Publ. No. 84, *Measurement of luminous flux*, 1989.

Papamichael, K.M., Klems, J., Selkowitz, S.; *1988. Determination and Application of Bi-directional Solar-optical Properties of Fenestration Systems*, Proc. of 13th National Passive Solar Conference, Cambridge, MA.

Tregenza, P. R., *1987. Subdivision of the Sky Hemisphere for Luminance Measurements*, Lighting Research and Technology 19-1, pp. 13-14.

8.3. Optical Characteristics of Daylighting Materials

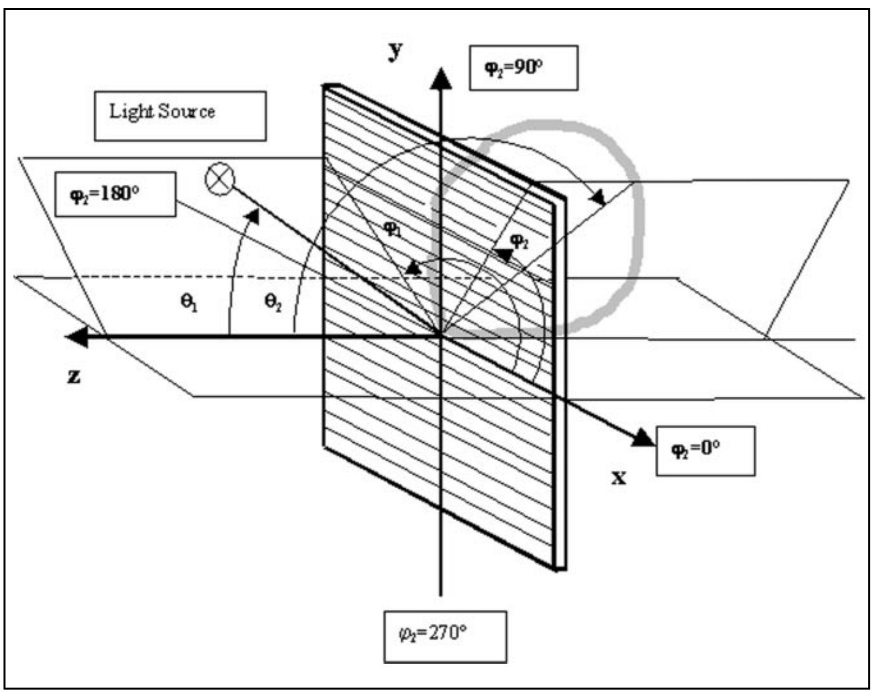
This appendix describes methods used to present and format measured optical performance data for daylighting systems, including 1) directional luminous transmittance measurements and 2) bi-directional transmittance distribution measurements. These data can be used in daylight simulation programs such 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 φ and altitude angle θ (similar to spherical coordinates).

Figure 8-3.1: Coordinate system for material measurements



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 φ is from 0° to 360°; θ varies between 0° and 90° for light incidence and from 90° to 180° 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 $\varphi_1 = 0°$ 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 φ_1 and θ_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 φ_1 and θ_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
#Isym=4 ! 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+001    2.424242e-002
0.000000e+000    1.250000e+001    2.272727e-002
0.000000e+000    1.500000e+001    2.272727e-002
0.000000e+000    2.000000e+001    2.121212e-002
0.000000e+000    2.500000e+001    2.045455e-002
0.000000e+000    3.000000e+001    1.893939e-002
0.000000e+000    3.500000e+001    1.818182e-002
```

END

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 τ_{dif} 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:

$$\tau_{dif} = \frac{1}{2\pi} \int_{\varphi_1=0}^{2\pi} \int_{\theta_1=0}^{\frac{\pi}{2}} \tau(\varphi_1, \theta_1) \cdot \sin(2\theta_1) \cdot d\theta_1 \cdot d\varphi_1$$

For a rotation symmetrical light transmittance:

$$\tau_{dif} = \int_{\theta_1=0}^{\frac{\pi}{2}} \tau(\theta_1) \cdot \sin(2\theta_1) \cdot d\theta_1$$

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.

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

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.

Table 8-3.1: Light incidence for bi-directional measurements

θ_1	φ_1-step	φ_1	**Light incidents must be measured for:**
0°	-	0°	All samples
12°	60°	0°, 60°	All samples
24°	30°	0°, 30°, 60°, 90°	All samples
36°	20°	0°, 20°, 40°, 60°, 80°	All samples
48°	15°	0°, 15°, 30°, 45°, 60°, 75°, 90°	All samples
60°	15°	0°, 15°, 30°, 45°, 60°, 75°, 90°	All samples
72°	12°	0°, 12°, 24°, 36°, 48°, 60°, 72°, 84°	All samples
84°	12°	0°, 12°, 24°, 36°, 48°, 60°, 72°, 84°	All samples
			Additional Measurements if the sample is asymmetric to:
12°	60°	120°, 180°	φ_1= 90° / 270°
24°	30°	120°, 150°, 180°	φ_1= 90° / 270°
36°	20°	100°, 120°, 140°, 160°, 180°	φ_1= 90° / 270°
48°	15°	105°, 120°, 135°, 150°, 165°, 180°	φ_1= 90° / 270°
60°	15°	105°, 120°, 135°, 150°, 165°, 180°	φ_1= 90° / 270°
72°	12°	96°, 108°, 120°, 132°, 144°, 156°, 168°, 180°	φ_1= 90° / 270°
84°	12°	96°, 108°, 120°, 132°, 144°, 156°, 168°, 180°	φ_1= 90° / 270°
12°	60°	300°	φ_1= 0° / 180°
24°	30°	270°, 300°, 330°	φ_1= 0° / 180°
36°	20°	280°, 300°, 320°, 340°	φ_1= 0° / 180°
48°	15°	270°, 285°, 300°, 315°, 330°, 345°	φ_1= 0° / 180°
60°	15°	270°, 285°, 300°, 315°, 330°, 345°	φ_1= 0° / 180°
72°	12°	276°, 288°, 300°, 312°, 324°, 336°, 348°	φ_1= 0° / 180°
84°	12°	276°, 288°, 300°, 312°, 324°, 336°, 348°	φ_1= 0° / 180°
12°	60°	240°	φ_1= 0° / 180° **and** φ_1= 90° / 270°
24°	30°	210°, 240°	φ_1= 0° / 180° **and** φ_1= 90° / 270°
36°	20°	200°, 220°, 240°, 260°,	φ_1= 0° / 180° **and** φ_1= 90° / 270°
48°	15°	195°, 210°, 225°, 240°, 255°	φ_1= 0° / 180° **and** φ_1= 90° / 270°
60°	15°	195°, 210°, 225°, 240°, 255°	φ_1= 0° / 180° **and** φ_1= 90° / 270°
72°	12°	192°, 204°, 216°, 228°, 240°, 252°, 264°	φ_1= 0° / 180° **and** φ_1= 90° / 270°
84°	12°	192°, 204°, 216°, 228°, 240°, 252°, 264°	φ_1= 0° / 180° **and** φ_1= 90° / 270°

Note: For rotation symmetrical samples, only measurements for $\theta1$ = 0°, 12°, 24°, 36°, 48°, 60°, 72° and 84° 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 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: Vegla
#Isym=3 ! 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 Fachgebiet Lichttechnik, TUB
#measurements and processing by Berit Herrmann, Sirri Aydinli
#date of measurement: 29. September 1998
#contact aydinli@ee.tu-berlin.de  for details
#light incidence:
#phi_1: 0° (azimuth)
#theta_1: 0° (altitude)
#light transmittance: 0.45
```

[DATA SECTION]

```
#data
#phi_2          theta_2         btdf
0.000000e+000   9.590000e+001   2.497359e-002
0.000000e+000   9.940000e+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

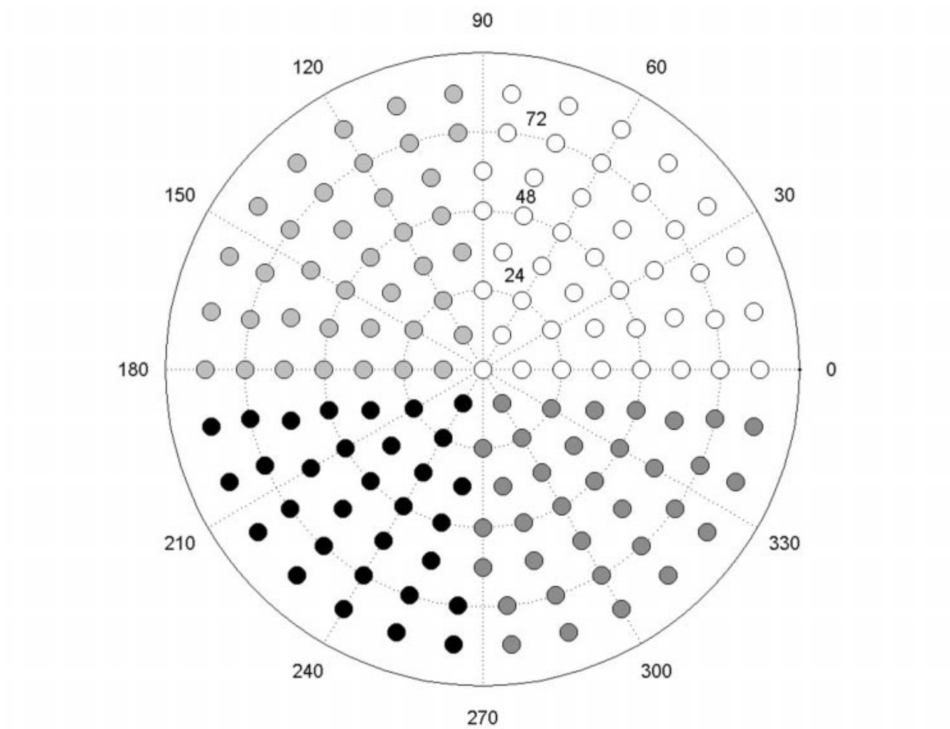


Figure 8-3.2: Light Incidence for bi-directional measurements

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 θ_1 and φ_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: θ_1 = 36° and φ_1 = 40°. 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.

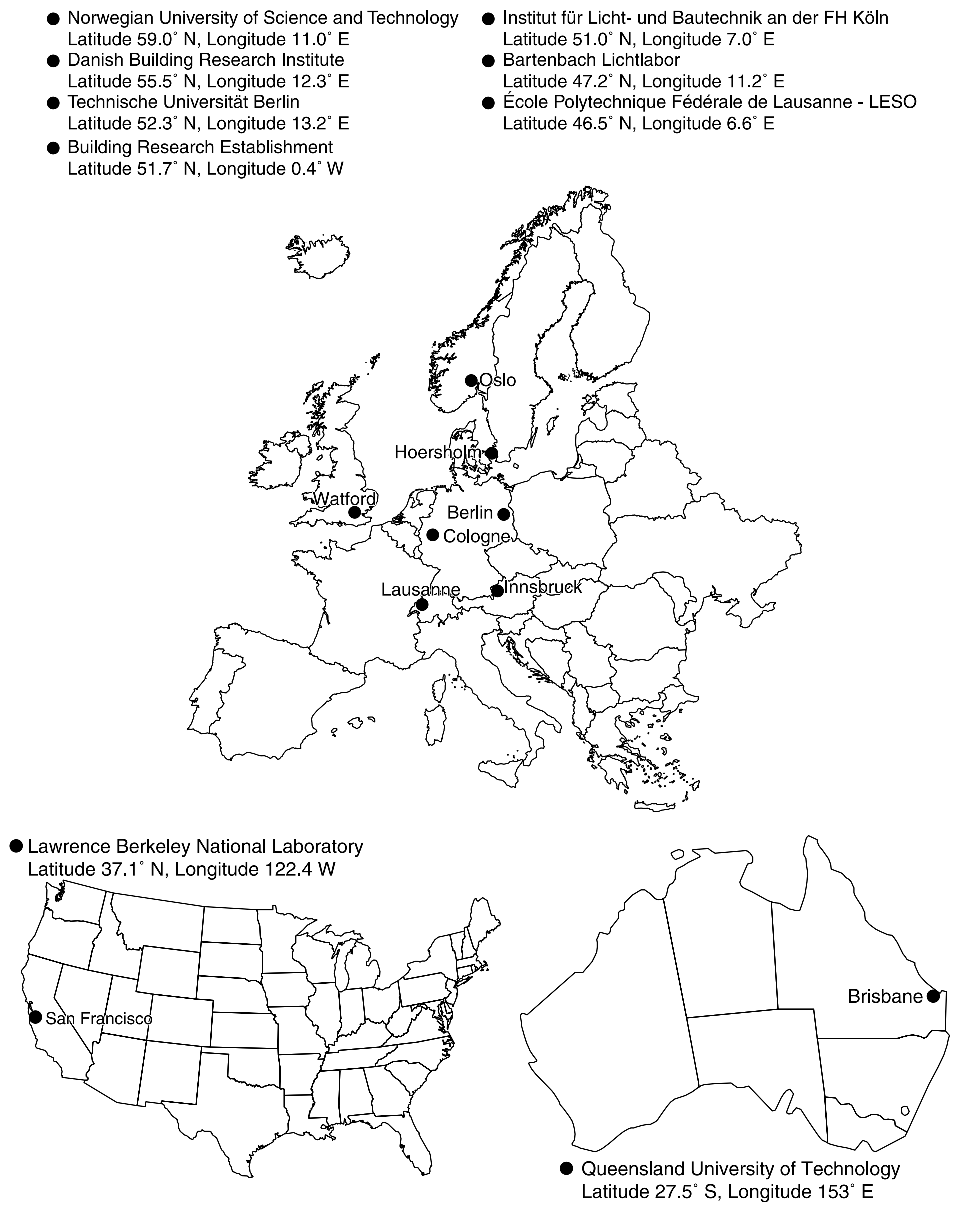


Figure 8-4.1: Map of test room locations

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.

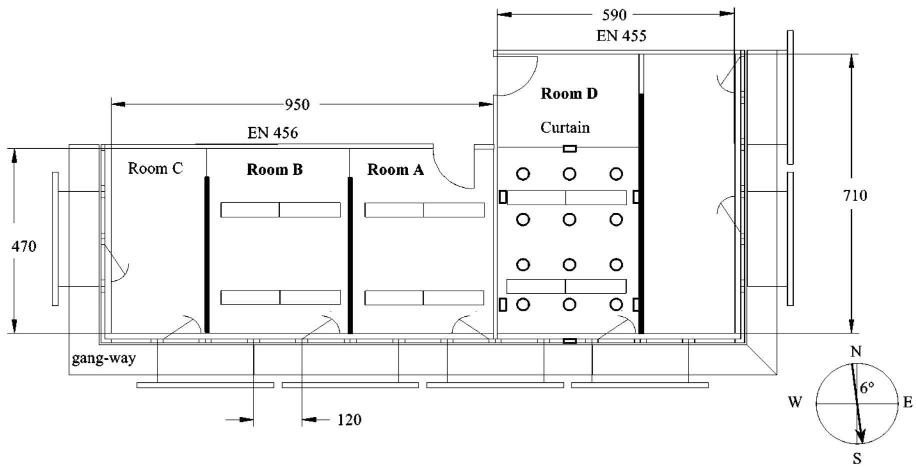


FIGURE 8-4.2: THE MOCK-UP OFFICES ARE MARKED ROOM A, B, AND D. GRID SENSOR POSITION IS SHOWN IN ROOM D. DIMENSIONS ARE GIVEN IN CM.

Test room: TUB	Length	Width	Height	Window area	Glazed area	Occupied
Geometry	4.70 m	3.50 m	3.00 m	7.00 m^2	5.30 m^2	No

Material Photometric Properties

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

Test room: TUB	Reflectance			Transmittance of glazing		
	Walls	Floor	Ceiling	τ_{dif}	$\tau_{\perp}$	U-value
Surfaces	50 %	20 %	80 %	70 %	80 %	1.7

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

Figure 8-4.3:
Exterior view of
TUB test rooms

Figure 8-4.4:
Interior view
of test room D
showing the window
configuration
and exterior
obstructions

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).

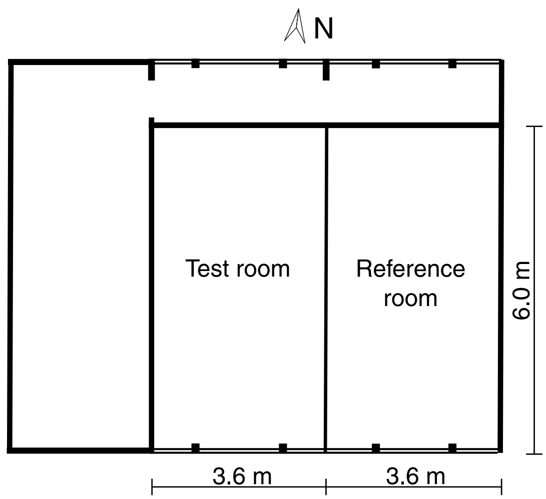


FIGURE 8-4.5:
FLOOR PLAN

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).

Test room: SBI	Length	Width	Height	Window area	Glazed area	Occupied
Geometry	6.00 m	3.60 m	3.00 m	7.80 m^2	6.60 m^2	No

Material Photometric Properties

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

Test room: SBI	Reflectance			Transmittance of glazing		
	Walls	Floor	Ceiling	τ_{dif}	$\tau_{\perp}$	U-value
Surfaces	79 %	29 %	89 %	65 %	72 %	1.1

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

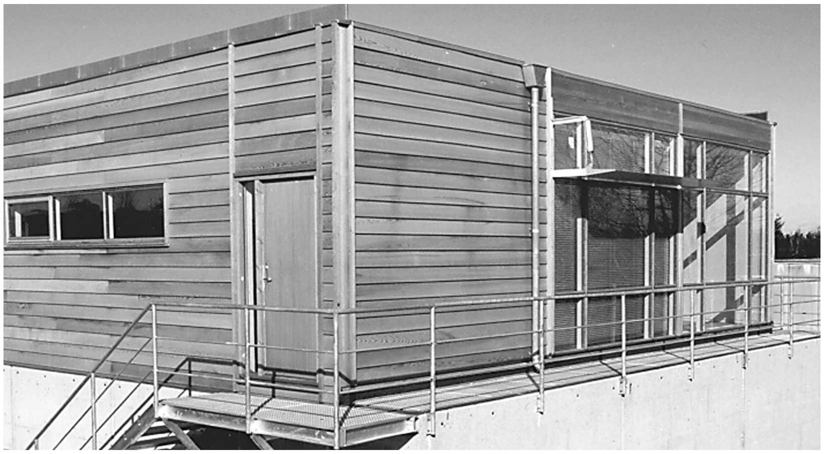


Figure 8-4.6: Exterior view of test rooms with the exterior light shelf

Figure 8-4.7: Interior view of test room showing the window configuration, arrangement of furniture for user acceptance studies, and exterior obstructions

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.

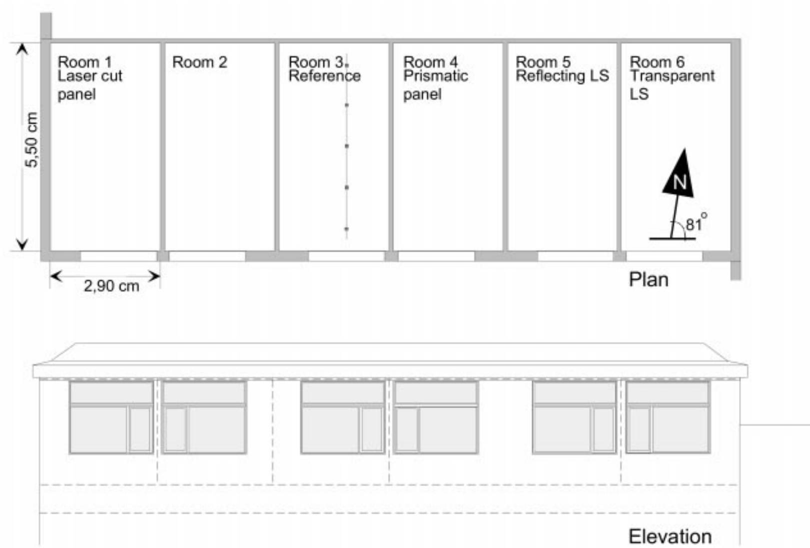


Figure 8-4.8: Plan and elevation of the Norwegian test rooms at the local energy company

Test room: NTNU	Length	Width	Height	Window area	Glazed area	Occupied
Geometry	5.90 m	2.90 m	2.70 m	4.30 m^2	3.20 m^2	Yes

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.

Test room: NTNU	Reflectance			Transmittance of glazing		
	Walls	Floor	Ceiling	τ_{dif}	$\tau_{\perp}$	U-value
Surfaces	69 %	18 %	82 %	77 %	NA	1.6

Note: τ_{dif} =transmittance for hemispherical irradiation;

$\tau_{\perp}$ = transmittance for normal irradiation;

U-value in W/m^2K.

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.

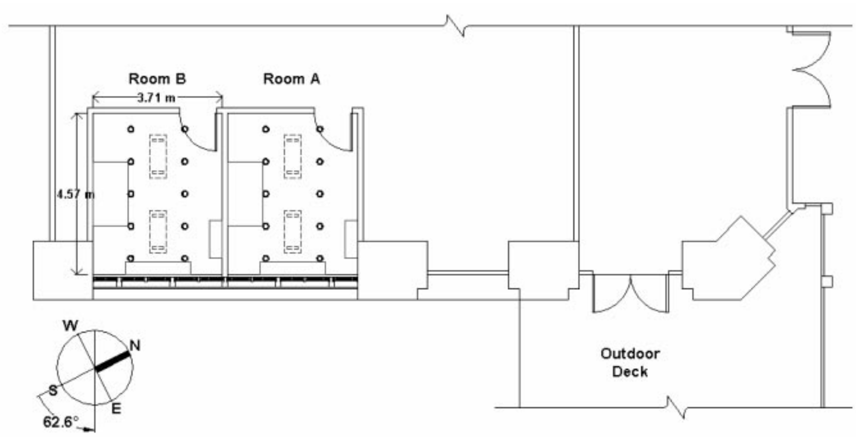
8.4.4. Lawrence Berkeley National Laboratory (LBNL), USA

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.

FIGURE 8-4.11:
PLAN AND SECTION OF TEST ROOMS CONFIGURATION



Test room: LBNL	Length	Width	Height	Window area	Glazed area	Occupied
Geometry	4.57 m	3.70 m	2.58 m	8.50 m^2	7.52 m^2	No

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.

Test room: LBNL	Reflectance			Transmittance of glazing		
	Walls	Floor	Ceiling	τ_{dif}	$\tau_{\perp}$	U-value
Surfaces	88 %	17 %	88 %	69 %	76 %	6.4

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

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.

Figure 8-4.12: Exterior view of the test rooms. The 18-storey tower on the left houses the LBNL test rooms on the fifth floor, with an adjacent 5-storey building wing to the north or right

Figure 8-4.13: Views in the LBNL test room with partially closed venetian blinds on a sunny day

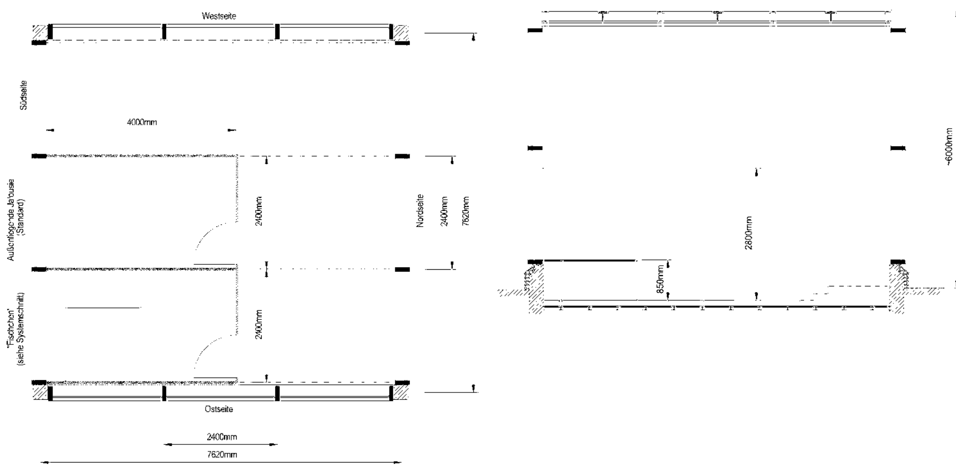
8.4.5. Bartenbach LichtLabor (BAL), Austria

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.

Figure 8-4.14: Plan and elevation of test room configuration



Test room: BAL	Length	Width	Height	Window area	Glazed area	Occupied
Geometry	5.00 m	2.30 m	2.80 m	4.50 m^2	4.50 m^2	No

Material Photometric Properties

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

Test room: BAL	Reflectance			Transmittance of glazing		
	Walls	Floor	Ceiling	τ_{dif}	$\tau_{\perp}$	U-value
Surfaces	80 %	30 %	80 %	85 %	92 %	-

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

Figure 8-4.15:
Exterior view of the test rooms at Bartenbach LichtLabor

Figure 8-4.16:
Interior view of test rooms with the Fish system (left) and the reference room (right)

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.

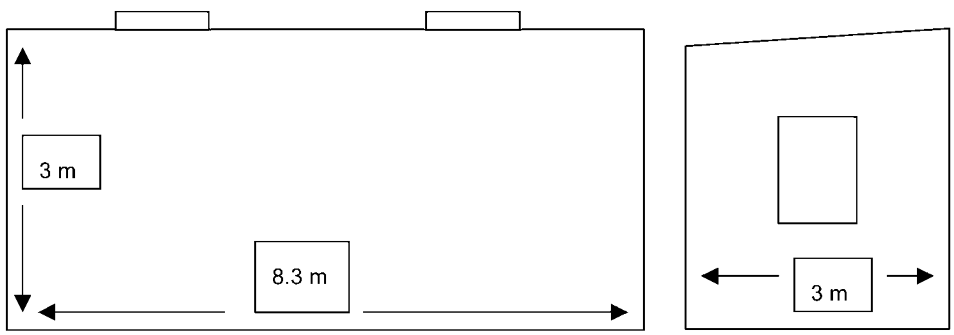
8.4.6. Queensland University of Technology (QUT), Australia

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



Test room: QUT	Length	Width	Height	Window area	Glazed area	Occupied
Geometry	8.00 m	3.00 m	3.00 m	1.20 m^2	1.20 m^2	No

Material Photometric Properties

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

Test room: QUT	Reflectance			Transmittance of glazing		
	Walls	Floor	Ceiling	τ_{dif}	$\tau_{\perp}$	U-value
Surfaces	60 %	30 %	80 %	85 %	92 %	-

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

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.

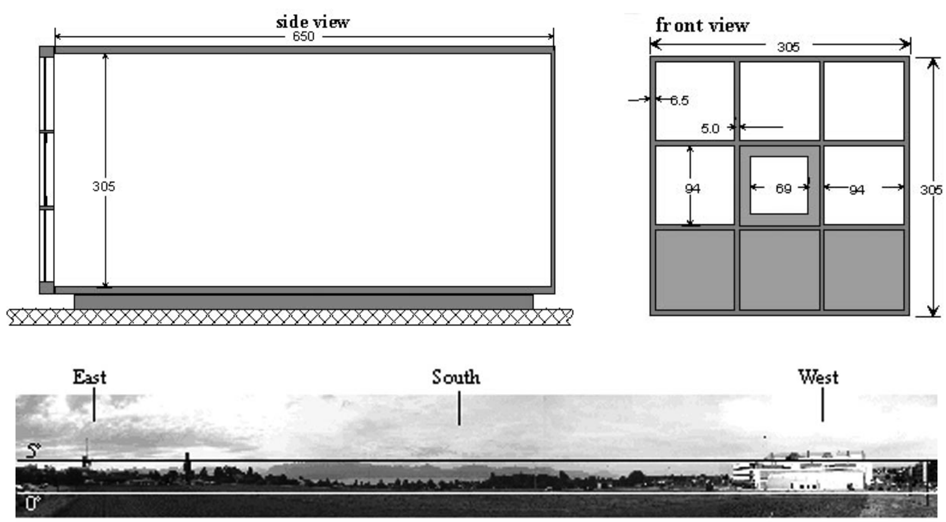


Figure 8-4.20: Elevations of the test rooms and view of the exterior obstructions. Dimensions are given in cm.

Test room: EPFL	Length	Width	Height	Window area	Glazed area	Occupied
Geometry	6.50 m	3.05 m	3.05 m	9.30 m^2	4.90 m^2	No

Material Photometric Properties

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

Test room: EPFL	Reflectance			Transmittance of glazing		
	Walls	Floor	Ceiling	τ_{dif}	$\tau_{\perp}$	U-value
Surfaces	81 %	16 %	81 %	70 %	80 %	2.9

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

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

Figure 8-4.22: Internal view of test room with the anidolic system

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.

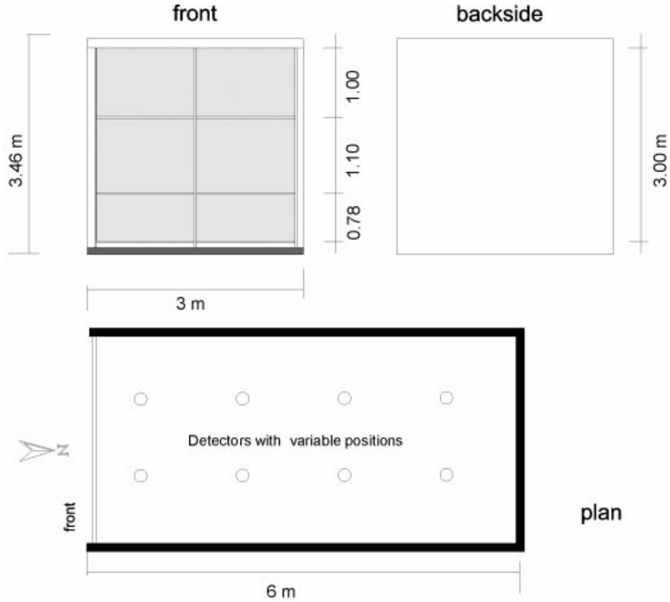


Figure 8-4.23: Elevations of test room (above) and floor plan (below)

Test room: ILB	Length	Width	Height	Window area	Glazed area	Occupied
Geometry	6.00 m	3.00 m	2.50 m	9.00 m^2	9.00 m^2	No

Material photometric properties

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

Test room: ILB	Reflectance			Transmittance of glazing		
	Walls	Floor	Ceiling	τdif	$\tau\perp$	U-value
Surfaces	70 %	30 %	80 %	70 %	80 %	3.0

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

Figure 8-4.24:
Exterior view of test rooms of ILB (9^{th} floor)

Figure 8-4.25:
Interior view of test room with sun-directing glass in upper aperture

Equipment for Measurement

All sensors used for interior and exterior illuminance measurements were light-sensitive silicon diodes with V(λ) 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.

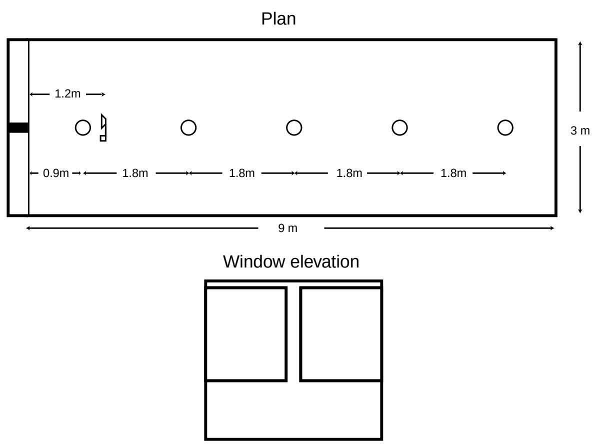


Figure 8-4.26: Plan and window elevation of a test room

Test room: BRE	Length	Width	Height	Window area	Glazed area	Occupied
Geometry	9.00 m	3.00 m	2.70 m	4.80 m^2	3.60 m^2	No

Material Photometric Properties

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

Test room: BRE	Reflectance			Transmittance of glazing		
	Walls	Floor	Ceiling	τ_{dif}	$\tau_{\perp}$	U-value
Surfaces	80 %	9 %	80 %	85 %	95 %	-

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

Figure 8-4.27: Exterior view of the test rooms. The four windows at the top right of the building belong to the two test rooms

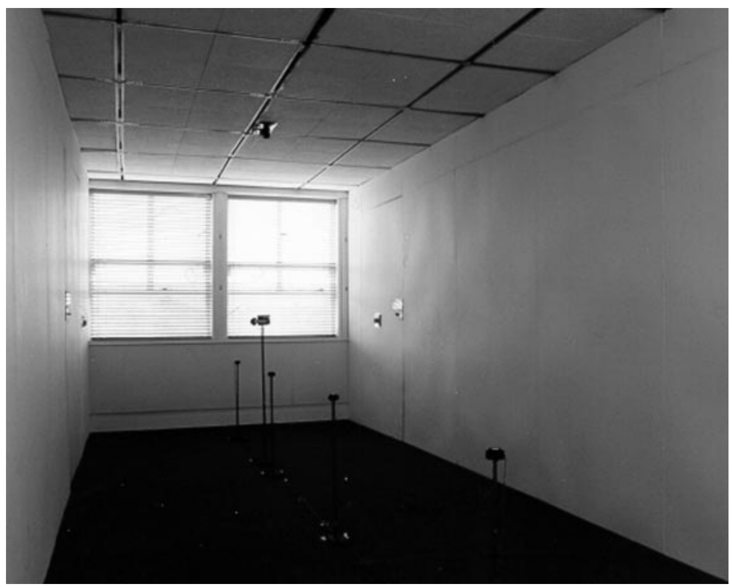


Figure 8-4.28: Interior view of test room

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

Institute	Manufacturer	Range klux	Calibration	Maximum calibration error	V(λ) (f_1')	Cosine response error (f_2)	Fatigue error (f_5)
Australia (QUT)	TopCon IM5	0.01 - 200	1998	± 2 %		± 5%	
Austria (BAL)	LMT	0.1 - 200	1994+1998	± 7 %	± 2%	± 2%	
Denmark (SBI)	Hagner	0.1 - 100	1993/1998		< 3%	< 3%	
Germany (ILB)	ILB	1.0 - 120		± 10 lux	< 3 %	< 0.4 %	< 1 %
Germany (TUB)	LMT	0.1 - 100	1996	± 0.6 %	< 3%	< 2%	
Norway (NTNU)	PRC Krochmann	50 - 200 2 - 100	1996	0.5 %	< 2%	< 1%	< 0.1 %
Switzerland (LESO)	BEHA	1.0 - 100	1996	2.5 %			2 %
	L.M.T.	1.0 - 100		3 %	3 %	2 %	
United Kingdom (BRE)	Megatron	0.01- 7.5/50 (depends on sensor position)	12 month interval	3 %	0.5%	3%	1%
USA (LBNL)	Li-Cor	0.0 - 150	1995	1%	-	1%	-

Description of Data Acquisition System

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

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.

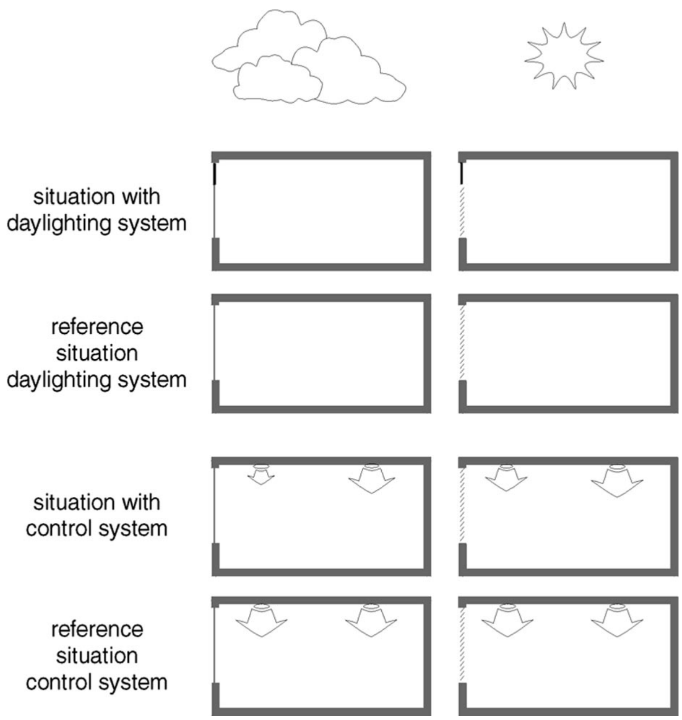


Figure 8-5.1: Basic assumptions for reference situation

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:

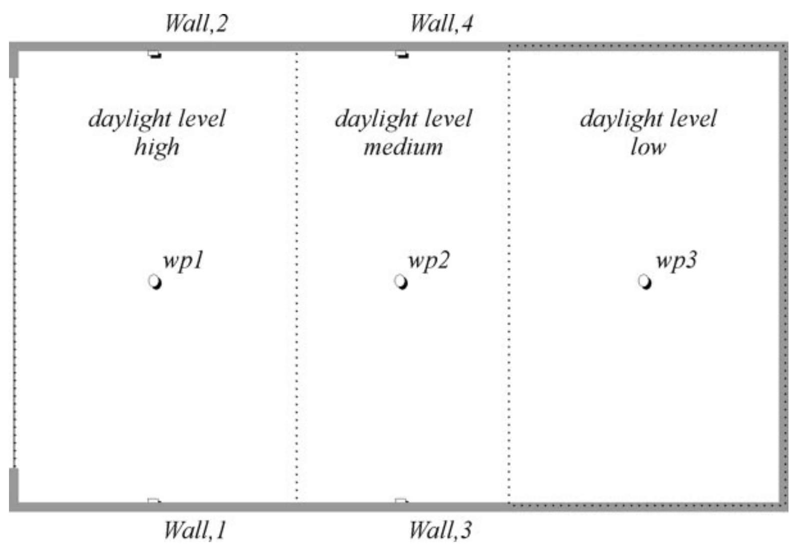
- A decision phase, in which choices are made regarding testing and the types of measurements to be carried out;
- A preparatory phase, in which the unchangeable conditions of the test rooms and monitoring equipment to be used are recorded in a descriptive document;
- A monitoring programme, which includes 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).

FIGURE 8-5.2: SENSOR POSITION FOR MONITORING A CONTROL SYSTEM



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 Jöspershecklein
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

Huppe Form GmbH
Sonnenschutz und Raumsysteme
Postfach 252326015 Oldenburg
Germany
Tel. +49 441 402282
Fax +49 441 402 454
Reflective blinds

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

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

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

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

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

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

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

Heliostats

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

Alternate Energy Institute
5333 Mission Center Rd. No. 351
San Diego, CA 92108
United States
Tel. +1 (619) 692-2015
Heliostats

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)

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

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)

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

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

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

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

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

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

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

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

Department of Physics
(Dr I Edmonds, Dr I Cowling)
Queensland University of Technology
GPO Box 2434
Brisbane Q 4001
Australia
Tel. +61 7 864 2329
Fax +61 7 864 1521
Laser-cut light deflecting sheets, stacked
curved daylight deflecting prisms

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)
Swiss Federal
Institute of Technology
in Lausanne (EPFL)
1015 Lausanne
Switzerland
Tel. +41 21 693 45 45
Fax +41 21 693 27 22
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