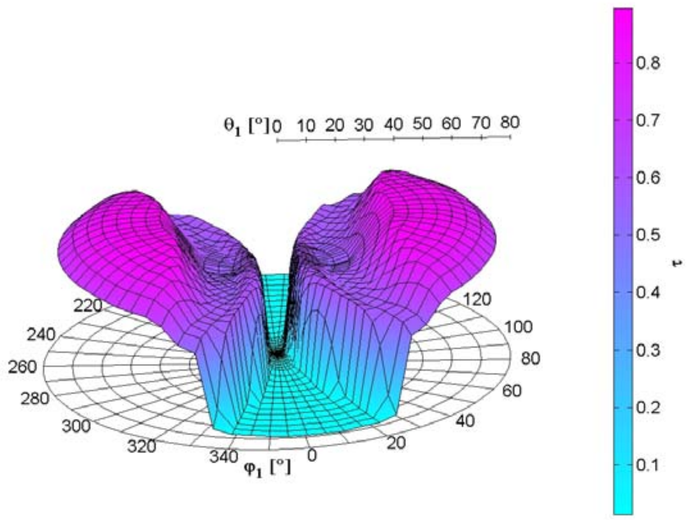
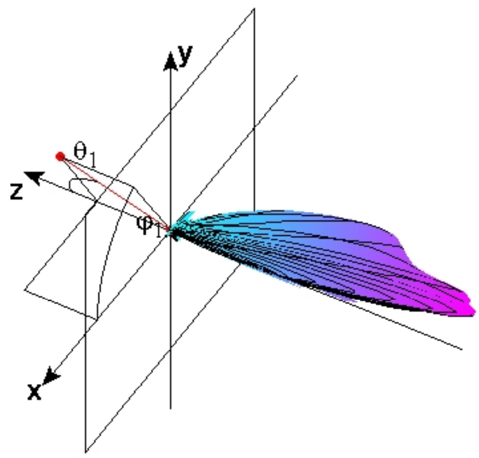
Measurement of Luminous Characteristics of Daylighting Materials

A Report
of IEA SHCP TASK 21 / ECBCS ANNEX29
September 1999





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Measurement of Luminous Characteristics of Daylighting Materials

International Energy Agency (IEA) Solar Heating and Cooling Programme Task 21 /

Energy Conservation in Buildings and Community Systems Programme Annex 29:

DAYLIGHT IN BUILDINGS

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PREFACE

The main objectives of the IEA Solar Heating and Cooling Programme (SHC) Task 21 and the Energy Conservation in Buildings and Community Systems Programme (ECBCS) Annex 29 "Daylight in Buildings" are to advance daylighting technologies and to promote daylight conscious building design. Since Task 21 is finished, it will endeavour to overcome the barriers that are impending the appropriate integration of daylighting aspects in building design. The participants in this task are Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Italy, Netherlands, New Zealand, Norway, Sweden, Switzerland, United Kingdom and the United States. Denmark is the Operating Agent.

The main objective of Subtask A “Performance Evaluation of Daylighting Systems” is to provide a Design Guide for building designer on the selection and appropriate integration of daylighting systems and strategies in new and renovated buildings. The resulting Design Guide will document the performance of the system tested, give information on system construction and maintenance, and recommendations on appropriate application of the different daylighting strategies under various climatic conditions. Subtask A is devided into 7 Subgroups:

A1: Survey of Systems
A2: Testing Procedures
A3: Pilot Studies
A4: Measurement of Physical Characteristics
A5: Test Room Studies
A6: Scale Model Studies
A7: Source Book

This report “Measurement of Physical Characteristics” was initiated and compiled within Subgroup A4.

EXECUTIVE SUMMARY

The document presents work conducted as part of Subtask A “Performance Evaluation of Daylighting Systems”, Subgroup A4, “Measurement of Physical Characteristics”, of the IEA SHC Task 21 and the ECBCS Program Annex 29 “Daylighting in Buildings”.

The planned use of daylight in buildings is nowadays a necessary strategy to minimise the energy for lighting, heating and cooling as well as to improve the comfort and visual performance in interiors. The use of daylight to replace or supplement electric lighting in buildings can result in significant energy savings. New innovative daylighting systems developed over the last fifteen years are used to control the daylighting in interiors, the solar radiation entering the interior as well as thermal losses and gains. For a good daylighting design in different climatic zones, the performance parameters of the used daylighting system have to be known.

The aim of the project is to measure the luminous quantities of daylighting components such as light transmittance and bi-directional transmittance distribution function (BTDF). The obtained data leads to the assessment of the capability of systems to utilise daylight. Subtask C will be provided with the necessary data for the development of algorithms to predict energy saving in buildings.

For this, the appropriate measuring facilities of the three different institutions are identified by carrying out the pilot measurements as well as analysing the possible error sources of the measurements. The measurements for selected daylighting components are carried out. The corresponding data stored in the agreed data format is enclosed on a CD that comes with this report.

CONTENTS

SYMBOLS

D 65	CIE standard illuminant to represent daylight
E	Illuminance on a medium ($lx = lm/m^2$)
f_1	$V(\lambda)$ match
f_2	Cosine response
g	Total solar energy transmittance (solar factor)
L	Luminance of a surface element (cd/m^2)
$L(\varphi_2, \varepsilon_2)$	Luminance of a surface element in the direction of the viewing (angles φ_2 and θ_2) (cd/m^2)
L_w	Luminance of a perfect reflecting or transmitting diffuser (cd/m^2)
qi	Secondary internal heat transfer factor
R_a	General color rendering index
R_i	Special color rendering indices (i = 1 .... 14)
$S(\lambda)$	Spectral power distribution of the radiation
$s(\lambda)_{rel}$	Relative spectral responsivity of a detector
T_{cp}	Correlated color temperature (K)
U	Thermal transmittance coefficient ($W.m^{-2}.K^{-1}$)
$V(\lambda)$	Spectral luminous efficiency
ϕ	Incident luminous flux (lm)
ϕ_τ	Transmitted luminous flux (lm)
$\phi_{\tau r}$	Regularly transmitted luminous flux (lm)
$\phi_{\tau d}$	Diffusely transmitted luminous flux (lm)
$\beta(\varphi_2,\theta_2)$	Luminance factor in the direction of the viewing (angles φ_2 and θ_2)
$q(\varphi_2,\theta_2)$	Luminance coefficient in the direction of the viewing (angles φ_2 and θ_2)
τ	Transmittance
$\tau(\varphi_1,\theta_1)$	Transmittance for given light incidence (angles φ_1 and θ_1)
τ_r	Regular Transmittance
τ_d	Diffuse Transmittance

τ_{dif}	Transmittance for hemispherical irradiation (diffuse incidence of radiation)
τ(D 65)	Transmittance for CIE standard illuminant D 65
τ_e	Solar transmittance
φ_1	Azimuth angle for light incidence
θ_1	Elevation angle for light incidence, measured from the normal to the surface
φ_2	Azimuth angle for viewing
θ_2	Elevation angle for viewing, measured from the normal to the surface

1 INTRODUCTION

The designed daylight utilisation in buildings is today very important to minimise the energy for lighting, heating and cooling as well as to improve the comfort and visual performance in buildings. The use of daylight to replace or supplement electric lighting in buildings can result in significant energy savings. New innovative daylighting systems developed over the last fifteen years are used to control the daylighting in interiors, the solar radiation entering the interior as well as thermal losses and gains.

Many problems in daylighting design for different climatic zones can nowadays be treated and solved with simulation software. For this, the performance parameters of the used daylighting system have to be known sufficiently.

Daylighting design in interiors with design tools can be carried out in three different ways (fig. 1). The methods differ from each other by the availability of the data of the daylighting system:

- The first possibility is the measurement of the luminous and radiant quantities of the daylighting material or particular elements of the daylighting system in dependence of light incidence. From this data, the corresponding quantities of the daylighting system can be determined by the computer simulation. The disadvantage of this way is the urge of a lot of simulation steps and the lack of the availability of corresponding data of the daylighting materials.

- The second possibility is the measurement of the radiant and luminous quantities of the whole daylighting system. The data can directly be used in design tools. The advantage of this way is less simulation steps in comparison with the first method. The disadvantage is the limitation of the measuring facilities especially for the movable daylighting systems.

- The third possibility is to test of the daylighting systems in test rooms under different sky conditions and in various seasons and at different daytimes. The advantage of this method is that the test of the corresponding daylighting system takes place under real conditions. The disadvantage is the extension of the test over a long time.

The aim of the project is to measure the luminous quantities of daylighting materials and components such as light transmittance and bi-directional transmittance distribution function (BTDF). The obtained data leads to the assessment of the capability of systems to utilise daylight. Subtask C will be provided with the necessary data for the development of algorithms to predict energy saving in buildings.

This document consist of four major points:

i. Definitions of the characteristics and principles of the measurement. The parameters affecting the characteristics and the measuring principles are pointed out.

ii. Description of the laboratory facilities: The laboratory facilities of different institutions and their capabilities are described.

iii. Pilot measurement and analysis of errors sources: The results of the pilot measurement of luminous characteristics (light transmittance and bi-directional transmittance), carried out in different laboratory facilities, and their comparison are stated. The results are analysed regarding the error sources.

iv. Measurement and data set of the luminous characteristics of selected daylighting materials.

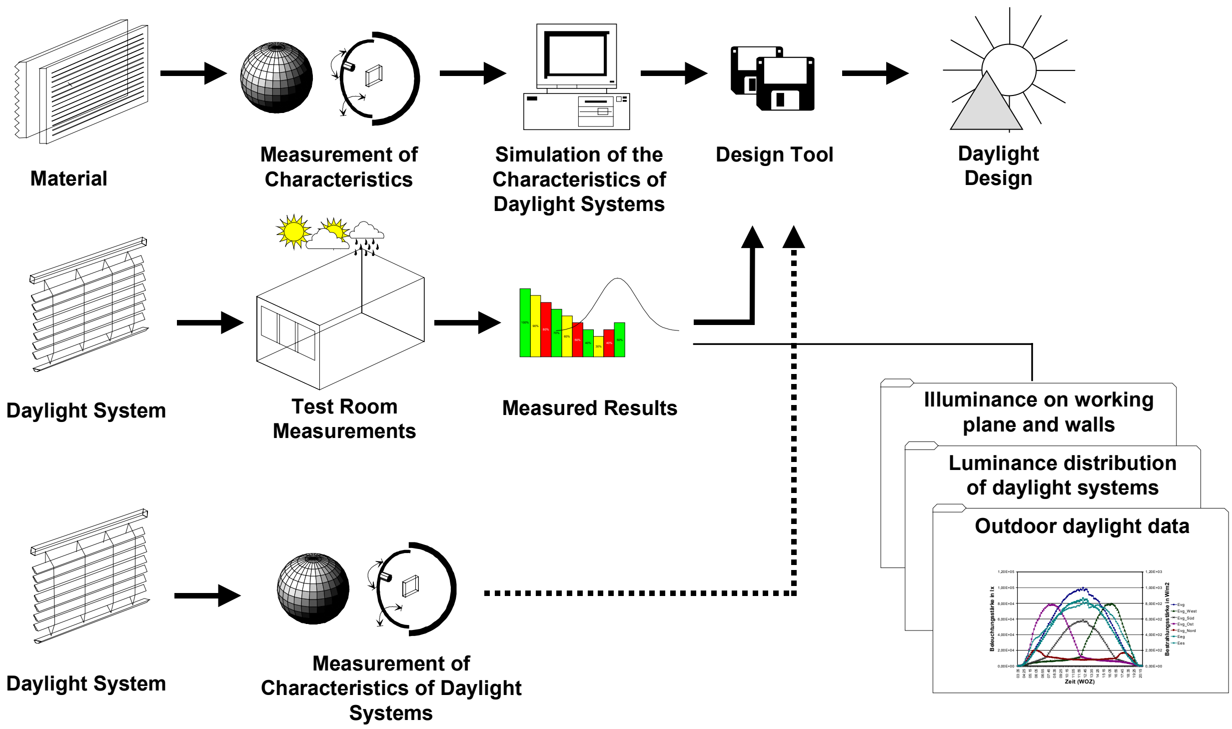

Fig. 1: The three methods for daylighting simulation

2 DEFINITIONS OF THE CHARACTERISTICS AND MEASUREMENT PRINCIPLES

The characteristics of materials are defined with respect to the International Lighting Vocabulary [1] and the relevant CIE publications : “Radiometric and Photometric Characteristics of Materials and their Measurement“ [2], “Absolute Methods for Reflection Measurements“ [3], “A Review of Publications on Properties and Reflection Values of Material Reflection Standards“ [4], and “ Practical Methods for the Measurement of Reflectance and Transmittance“ [5].

2.1 Definitions

2.1.1 Transmittance (845-04-59)*) (for incident radiation of given spectral composition, polarization and geometrical distribution)

Ratio of the transmitted luminous flux ϕ_τ to the incident flux ϕ in the given conditions.

symbol : τ
unit : *1 or (%)*

$$\tau = \phi_\tau / \phi \qquad (1)$$

Note - See Note 1 to 1.2.3

2.1.2 Regular Transmittance (845-04-61)*

Ratio of the regularly transmitted part of the (whole) transmitted flux $\phi_{\tau r}$, to the incident flux ϕ.

symbol : τ_r
unit : *1 or (%)*

$$\tau_r = \phi_{\tau r} / \phi \qquad (2)$$

Note - See Notes 1 and 2 to 1.2.3.

2.1.3 Diffuse Transmittance (845-04-63)*

Ratio of the diffusely transmitted part of the (whole) transmitted flux $\phi_{\tau d}$, to the incident flux ϕ.

symbol : τ_d
unit : *1 or (%)*

$$\tau_d = \phi_{\tau d} / \phi \qquad (2)$$

Notes 1. - $\phi_\tau = \phi_{\tau r} + \phi_{\tau d}$ *and* $\tau = \tau_r + \tau_d$
2. - *The results of the measurements of* τ_r *and* τ_d *depend on the instruments and the measuring techniques used.*

) Where a definition is taken from the International Lighting Vocabulary [1], the index number of this term in the Vocabulary is appended. Deviations from Vocabulary are indicated by an asterix ““.

2.1.4 Luminance Factor (845-04-69)* (at a surface element of a non-self-radiating medium, in a given direction, under specified conditions of illumination)

Ratio of the luminance of the surface element in the given direction $L(\varphi_2,\theta_2)$ to that of a perfect reflecting or transmitting diffuser L_w identically illuminated.

symbol : β
unit : 1

$$\beta(\varphi_2,\theta_2) = L(\varphi_2,\theta_2) / L_w \qquad (3)$$

Note. - See Notes to 1.2.5

2.1.5 Luminance Coefficient (845-04-71)* (at a surface, in a given direction, under specified conditions of illumination)

Quotient of the luminance of the surface element in the given direction $L(\varphi_2,\theta_2)$ by the illuminance on the medium E.

symbol : q
unit : ($cd.m^{-2}.lx^{-1}$) or (sr^{--1})

$$q(\varphi_2,\theta_2) = L(\varphi_2,\theta_2) / E \qquad (4)$$

*Note 1 - In the USA the concept **bi-directional reflectance distribution function (BRDF)** is similar to the above coefficient except that it is defined for directional incident radiation.*
Note2. - The luminance factor and luminance coefficient can be applied only in reference to scattered radiation [5]

2.2 Parameters Affecting the Characteristics

The characteristics are not specific properties of a material since they also depend on other parameters, such as geometry. They are, in fact, “characteristics of non-primary sources“ [2].

In general, the characteristics depend on the following facts :

2.2.1 Spectral Parameters

Spectral Composition of the Incident Radiation

The spectral power distribution of the incident radiation $S(\lambda)$ shall be specified, e.g. by naming the illuminant [6] or by its distribution temperature [1].

Standard Illuminants [6] are tabulated values of relative spectral power distributions which are not always realizable in a practical form. The symbol of illuminant can be added to the symbol of the quantity, e.g. τ(D 65) for the luminous transmittance with Standard Illuminant D 65.

Relative Spectral Responsivity of the Detector

The value of the characteristic to be measured depends strongly on the relative spectral responsivity [7] $s(\lambda)_{rel}$ of the detector used for the measurement. A photometric characteristic could be preceded by the adjective "luminous", e.g. luminous transmittance, and obtained by $s(\lambda)_{rel} = V(\lambda)$.

2.2.2 Geometric Conditions

The measured value of a characteristic depends on the measuring geometry, which must be specified by [2]

- direction of light incidence (angles φ_1 and θ_1) and of viewing direction (angles φ_2 and θ_2) (fig. 2).

- aperture of the incident and the observed beam.

The cone angles (apertures) of the incident and viewing beam must both be specified if they are larger then the prescribed values.

For hemispherical irradiation the index "dif" is used, e.g. transmittance for diffuse incidence of radiation τ_{dif}

Note : In special cases the index "d" is used instead of "dif" [6]

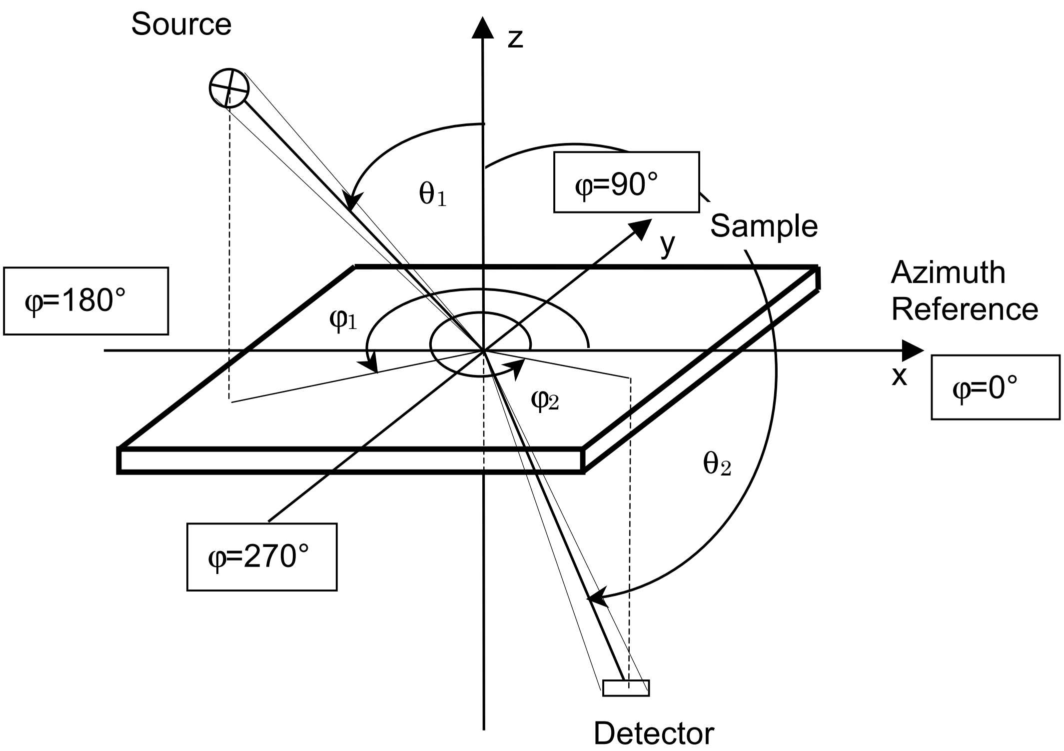

Fig. 2 : Angle notation for photometric properties

2.2.3 Other Parameters

Some other parameters are influencing the measured value of a specified characteristic [2]:

- The state of polarization of the radiation.
  If a characteristic is not determined with non-polarized radiation, the state of polarization and the azimuth of the plane of polarization must be specified. The reflected or transmitted radiation is usually partly polarized even if the incident radiation is non-polarized.

- The sample's thickness.
  If necessary, the thickness of the sample must be given. For tinted or coated materials the type and thickness of the coating must be given.

- The temperature.
  Characteristics are normally given for an ambient temperature of 25° C, if no other temperature is specified.

- State of the surface.
  Characteristics are normally given for a clean and dry sample, if nothing else is specified.

2.3 Measurement Principles

2.3.1 Absolute and Relative Methods

Since they are defined as the ratio of two fluxes, reflectance and transmittance are, in themselves, relative characteristics, but, whenever their values are measured directly without the use of another material standard as a reference, the corresponding method is termed "absolute".

Diffuse reflectance measurements are generally carried out with the help of a standard and are accordingly classified as relative methods. Absolute methods do exist [3], but they are normally restricted to standards laboratories, where they are used to make accurate calibrations of standards.

2.3.2 Spectral and Integral Characteristics

Spectral Method

With the spectral method, the relevant spectral characteristic, e.g. $\tau(\lambda)$ is measured as a function of the wavelength using as narrow a bandwidth as possible.

Integral Method

With the integral method the relevant weighted characteristic is measured directly, using a source having the prescribed spectral power distribution $S(\lambda)$ and a detector with the required relative spectral weighting function, e.g. $V(\lambda)$ for luminous characteristics and Standard illuminant A.

2.3.3 Spatial Evaluation

Characteristics with hemispherical or conical incidence or collection of radiation can be measured using:

- Goniophotometers
- Integrating sphere photometers
- Directional methods

2.4 Measuring Facilities

Characteristics dependent light incidence and observation of radiation can be measured with :

- Goniophotometers

- Integrating sphere photometers

2.4.1 Goniophotometers

With goniophotometric measurements the radiation transmitted by the sample into different directions is measured in these directions. If necessary, the angular data can then be mathematically integrated (e.g. to yield the transmitted luminous flux).

2.4.2 Sphere Photometers

In sphere photometers the radiation transmitted by the sample into all directions is collected and spatially integrated by the sphere.

2.5 Measurement of Transmittance τ

Generally these measurements are carried out with integrating sphere photometers. The measurements with a goniophotometer are often time consuming, expensive and must be made by experienced persons.

2.5.1 Measurement with Sphere Photometer

According to the theory of Ulbricht, the luminous flux, transmitted by a sample is directly proportional to the indirect illuminance on the inner surface of the integrating sphere. The luminous flux transmitted by a sample as well as the incident luminous flux on the sample can be measured with a photometer equipped with an integrating sphere, by comparison to the flux of a standard.

The sample is positioned at a special sphere port. The direct irradiation of the acceptance area of the photometer head by transmitted radiation must be avoided by a screen.

The coating for the inside of the sphere should reflect sufficiently diffuse and non-selective and must be uniform over the sphere’s surface. For the measurement of luminous characteristics it is recommended to choose a coating with a reflectance of about 0.8 [8].

For practical reasons, the sphere diameter should be as small as possible, but as large as necessary. It is recommended to use a sphere with a diameter D of $D \geq 10$ times the sample port diameter.

Measurements with an integrating sphere with a large sample port (compared to the sphere diameter as above) can be made only according to the substitution method. This method tries to eliminate the influence of the changed average sphere reflectance (by different reflectance of sample and standard). It requires the so-called “auxiliary screen (lamp) measurement“.

In case of thick transmitting samples (particularly diffusing and with a structured surface), the transmitted flux may not entirely enter the sphere due to internal refractions and scattering. The illuminated sample area must be smaller than the sample port area. Therefore, particularly large sample ports are often required, resorting to the substitution method and large sphere diameters. A sphere diameter $D \geq 0.5$ m is recommended especially for the measurement of thick transmitting samples.

2.5.2 Measurement of τ as a Function of Light Incidence

For the measurements of $\tau(\varphi_1,\theta_1)$ as a function of the angles of incidence, the equipment for irradiation must either be turned around the center in the outside plane of the sample, or the integrating sphere must be turned around a vertical axis at the sample surface on the sample port (change of θ_1 angle). Additionally, the sample must be turned around a horizontal (perpendicular to the sample’s surface) axis (change of φ_1 angle).

2.5.3 Measurement of τ_{dif}

For the measurement of the transmittance (τ_{dif}) of hemispherical irradiation, the irradiation equipment consists of a hemisphere (or a sphere) by which the sample is irradiated by a nearly uniform luminance from the hemisphere.

The transmittance (τ_{dif}) of hemispherical irradiation can be also calculated from the measured function of $\tau(\varphi_1,\theta_1)$.

$$\tau_{dif} = \frac{1}{2\pi} \int_{\varphi_1=0}^{2\pi} \int_{\theta_1=0}^{\pi/2} \tau(\varphi_1,\theta_1) \cdot \sin 2\theta_1 \cdot d\theta_1 \cdot d\varphi_1 \qquad (5)$$

For samples that are isotropic with respect to the azimuth of the incident radiation, τ is independent of φ_1. In this case, the double integral in equal (5) is simplified to the single integral:

$$\tau_{dif} = \int_{\theta_1=0}^{\pi/2} \tau(\theta_1) \cdot \sin 2\theta_1 \cdot d\theta_1 \qquad (6)$$

2.6 Bi-directional Transmittance Distribution Function (BTDF)

The BTDF is defined as the spatial distribution of luminance $L(\varphi_2,\theta_2)$ (luminance factor $\beta(\varphi_2,\theta_2)$ or luminance coefficient $q(\varphi_2,\theta_2)$) dependent on the angles of viewing angles φ_2 and θ_2 for given light incidence (angles φ_1, and θ_1).

These measurements can only be applied in reference to scattered radiation and carried out with goniophotometers (described in [9, 10, 11]).

From the measured values of BTDF (luminance coefficient $q(\varphi_2,\theta_2)$), the light transmittance $\tau(\varphi_1,\theta_1)$ for given light incidents (φ_1, and θ_1) can be calculated :

$$\tau(\varphi_1,\theta_1) = \frac{1}{2}\int_{\varphi_2=0}^{2\pi}\int_{\theta_2=0}^{\pi/2} q(\varphi_2,\theta_2)\cdot \sin 2\theta_2 \cdot d\theta_2 \cdot d\varphi_2 \qquad (7)$$

2.7 Spectral Measurements

2.7.1 In Visible Wavelength Range

For a selective transmittance (e.g. sun protecting glazing), this spectral measurement can be necessary to determine the color and color rendering properties of daylight in the interior. These are the correlated color temperature T_{cp} and CIE 1974 general color rendering index R_a and special color rendering indices R_i of the light transmitted by the daylight system for illumination by standard illuminant D 65 [6]

2.7.2 In Solar Radiation Wavelength Range (300 nm - 2500 nm)

With these measurements, the total energy transmittance g at a known thermal transmittance coefficient (U-value) can be determined [12].

2.8 Radiant and Thermal Properties

The radiant and thermal situation in the interior is strongly influenced by the radiant and thermal characteristics of daylighting systems. These are

- Solar (radiant) transmittance τ_e
- Thermal transmittance coefficient (U-value)
- Secondary internal heat transfer factor q_i
- Total solar energy transmittance (solar factor) $g = \tau_e + q_i$

For the determination of the properties of these glazings, there are different standard methods of calorimetric measurements and calculations [12,13]. In principle, these methods can also be used for daylighting systems.

3 MEASUREMENTS

3.1 Geometrical Description

In order to characterize any daylighting system with respect to different incident and observation angles, a co-ordinate 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 co-ordinates).

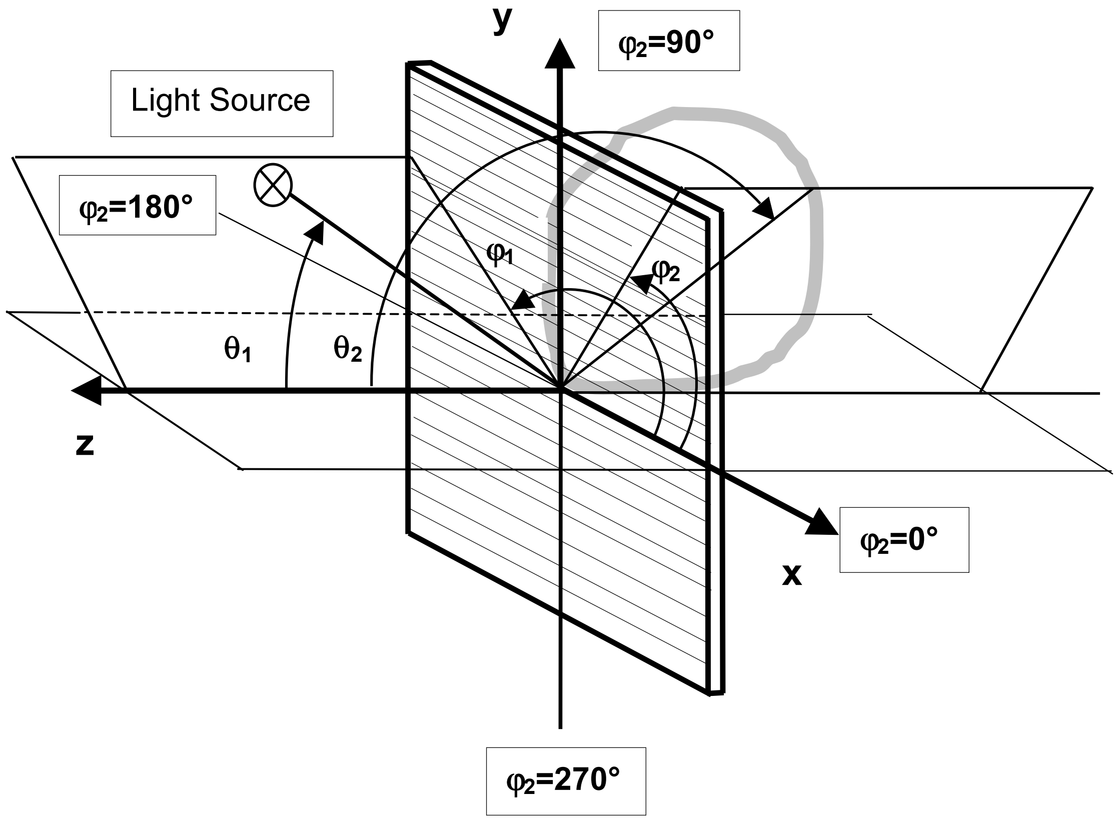

Fig. 3: Co-ordinate system for material measurements

An angle's index indicates whether it is related to the incident or the observation direction; index 1 is the incident direction and 2 is the observation direction, respectively.
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, respectively.The relative position of any daylight element to this co-ordinate system is of huge impact to the measurement results. Therefore, not only the co-ordinate 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 according real daylight system, e.g. the structure of a laser cut panel is usually horizontal, so φ_1 = 0° in the experimental setup will show horizontal structures as well
- The positive z-axis is the outside direction of the sample

4 LIGHT TRANSMITTANCE (DIRECTIONAL) MEASUREMENTS

For the measurement of selected daylighting systems' transmittance dependent on the light incidence, the following measuring facilities of different institutes are available.

4.1 Short Description of the Measuring Facilities

4.1.1 Description of the Ulbricht Integrating Sphere for Measurement of Hemispherical Transmittance of Glazing Systems (EPFL)

Location

Solar Energy and Building Physics Laboratory (LESO-PB)
Swiss Federal Institute of Technology (EPFL)

Integrating sphere

Diameter : 1.5 m.
Swiveling 180° on a horizontal axis (angle ε or θ),
passing through the sphere at the center
Placed on a movable mechanical support (rolling wheels), allowing the choice of different azimuth angles (angle φ)
White diffusive paint inside (ρ = 0,8)

Sample holder

Maximal aperture diameter 30 cm,
adjustable to 5, 10, 15, 20 and 25 cm
Maximal size of glazing samples for holder: 40 cm

Photometer

Krochmann mini sensor, sensitive area: ∅ 6 mm
Placed at 90° angle of opening with an in-between baffle
f1' Photopic correction : 2%; f2 cosine response : 1,5%

Transmittance values

Light beam incidence :
θ - angle from 0 to 90° (5° steps)
φ – angle from – 180 to + 180° (25° steps)

Light source

HMI Metallogen light bulb (2.5 kW), placed in a spotlight projector
(Fresnel and hyperbolic reflector).
Color temperature of 5600 K
Illuminance uniformity on a 30 cm diameter sample : better than 2%.

4.1.2 Measurement of Angle-dependent Transmittance at Fraunhofer ISE, Freiburg

The angle-dependent solar and light transmittance $\tau_{dh}^{S}(\Theta)$ and $\tau_{dh}^{L}(\Theta)$ have been determined with an integrating sphere using a pyroelectric radiometer and a photometer consisting of a photodiode with a V(λ)-correction filter glass. The polar angle Θ (incidence angle) had been varied from 0° to 75° in steps of 5°. The hemispherical reflectance ρ_{hh} of the back side of the samples for incident diffuse radiation (originating from the integrating sphere) has been determined for the samples with the Diffuse Radiation Source DRS using a sample port aperture of 10cm diameter; this value is needed for the second order correction stemming from the change of sphere throughput due to the sample at the measurement port.

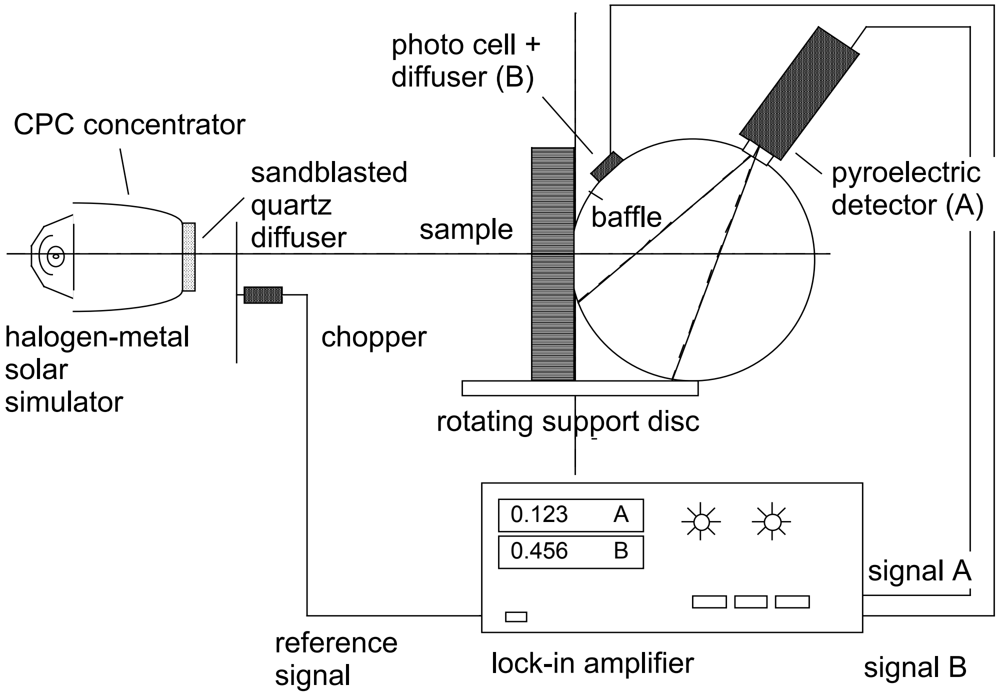

Fig. 4: Principle of the monitoring system

Diameter of the sphere : 0.8 m.
Reflectance of the inner sphere wall : 0.8

4.1.3. Integrating Sphere for the Measurement of Light Transmittance and Reflectance Dependent on Light incidence (TU B)

Sphere :

- diameter : 1.5 m

- swiveling 180° on a vertical axis at the sample surface P or P´ for the variation of the light incidence angle θ_1 (at P 0°- 90° for transmittance, at P´ 90°- 180° for reflectance)

- movable (adjustable) up to 30 cm on the horizontal X-axis for the thick samples

- reflectance of the interior of the sphere: non-selective, diffuse with ρ = 0.80

Sample holder :

- aperture diameter : max. 50 cm; changeable to 30, 20, 15 and 10 cm

- swiveling ±180° on the X-axis for the variation of the light incidence angle φ_1

Detector :

- photoelement with V(λ)- , cos - evaluation and shutter

Transmittance :

- light incidence : φ_1-angle ±180° in 5°-steps
  θ_1-angle from 0° - 75° (85°) free adjustable

Reflectance :

- light incidence : φ_1-angle ±180° in 5°-steps
  θ_1-angle : 8°, 20°-70°, in 10°-steps

Light source :

- incandescent lamp (125 W, 12 V) with optic

- adjustment on the CIE standard illuminants A and D65 (with colored filters)

- illuminated area on samples with diameters of 5, 10, 15 and 20 cm

Adjustment of the light incidence angles φ_1 and θ_1: manually

In order to eliminate the influence of different reflectances of samples and standards, the so called „auxiliary screen (lamp) measurement“ is possible

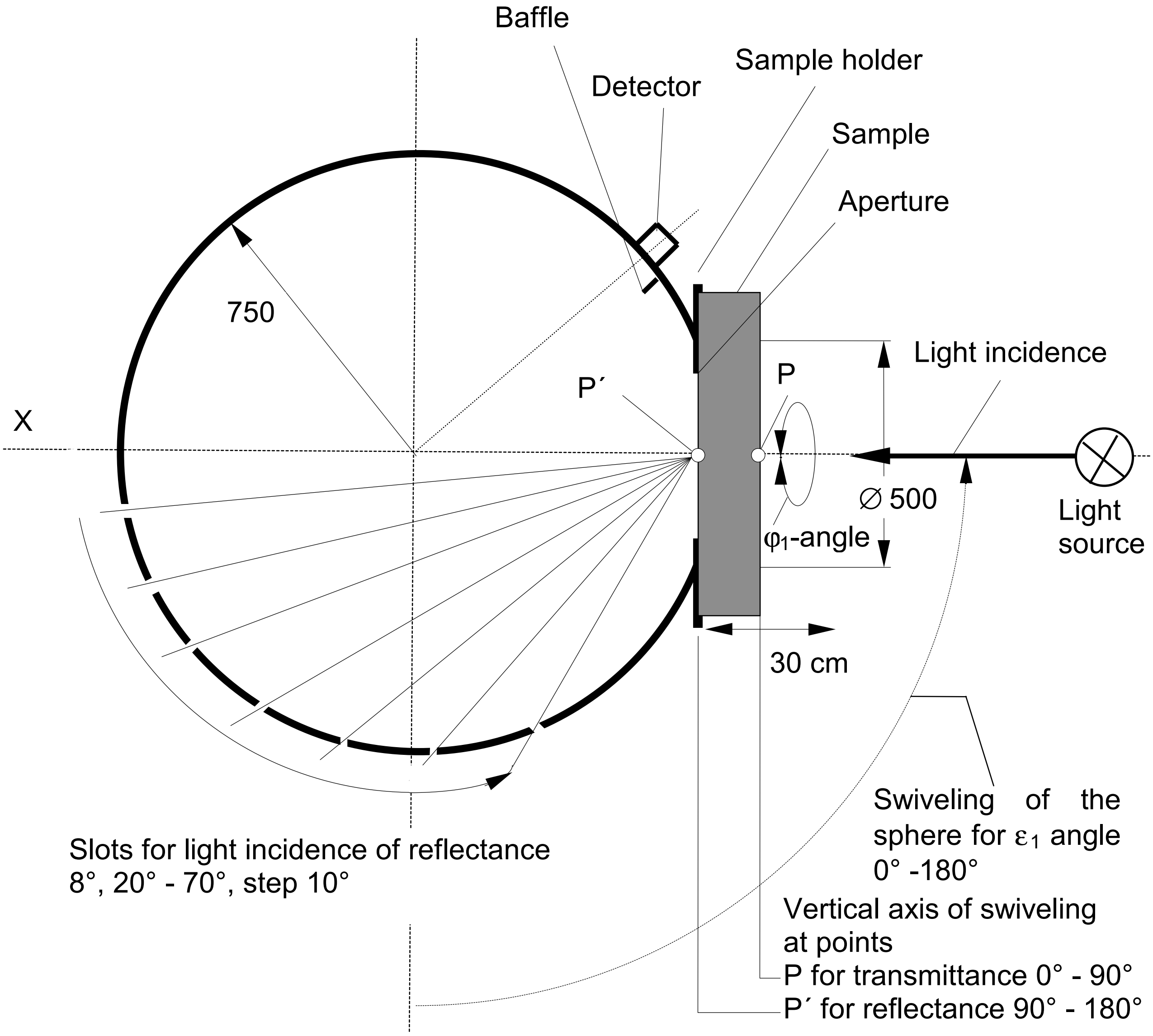

Fig. 5: Top view of the integrating sphere

4.2 Pilot Measurements

In order to be able to compare the measurements of the different institutes, two optical elements have been chosen for pilot measurements: a prismatic film from 3M (SOLF) and a Lambertian diffuser (Plexiglas, GS, weiss 060, 6 mm thick). The samples are sent to the respective institutes by ILB.

4.2.1 Comparison of Measuring Results

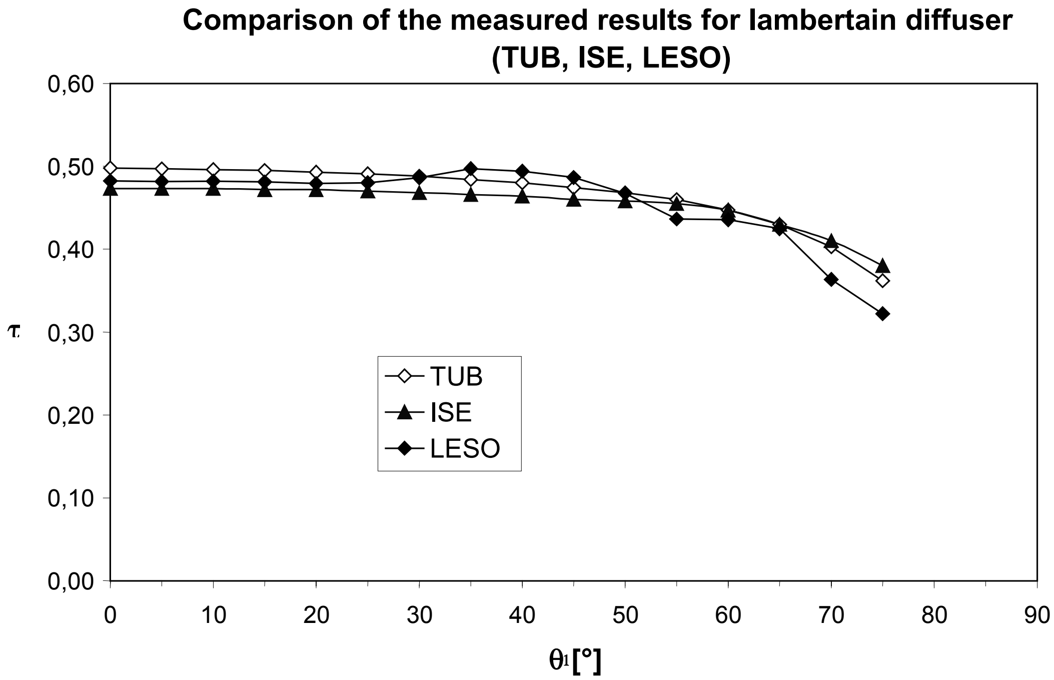

Fig. 6

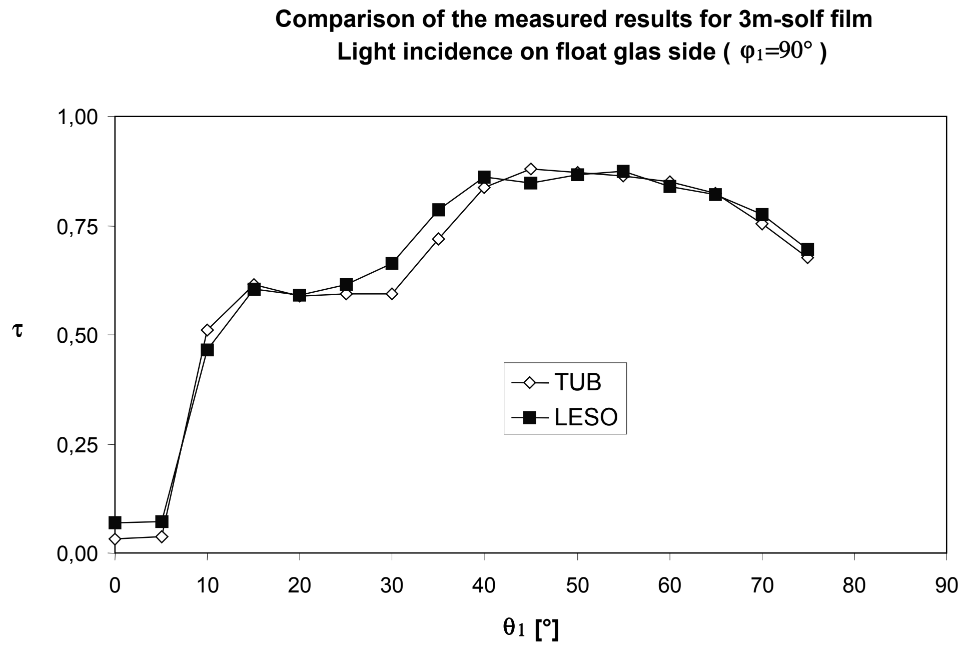

Fig. 7

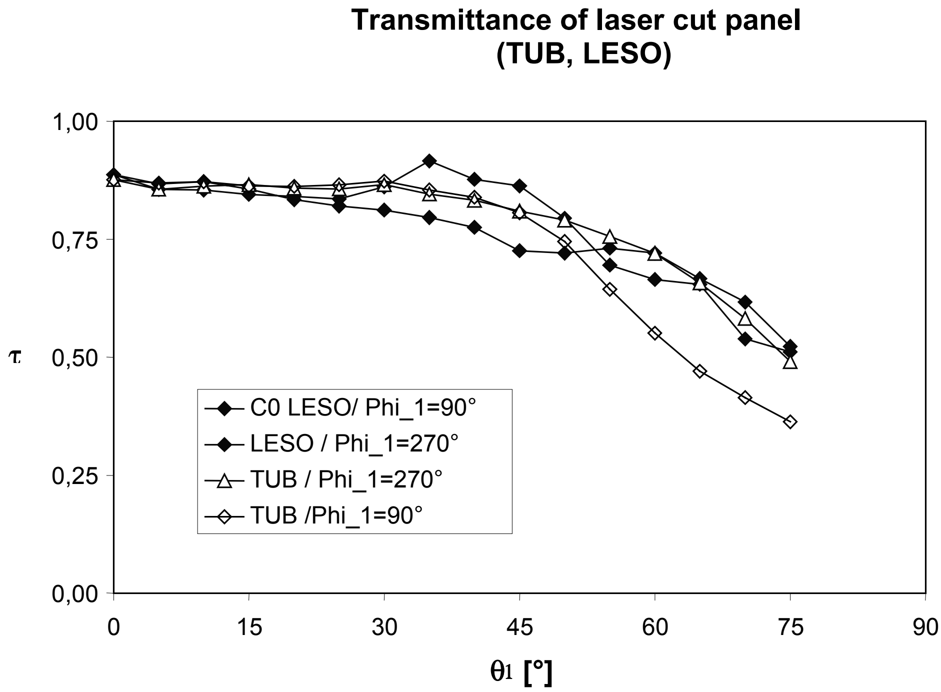

Fig. 8

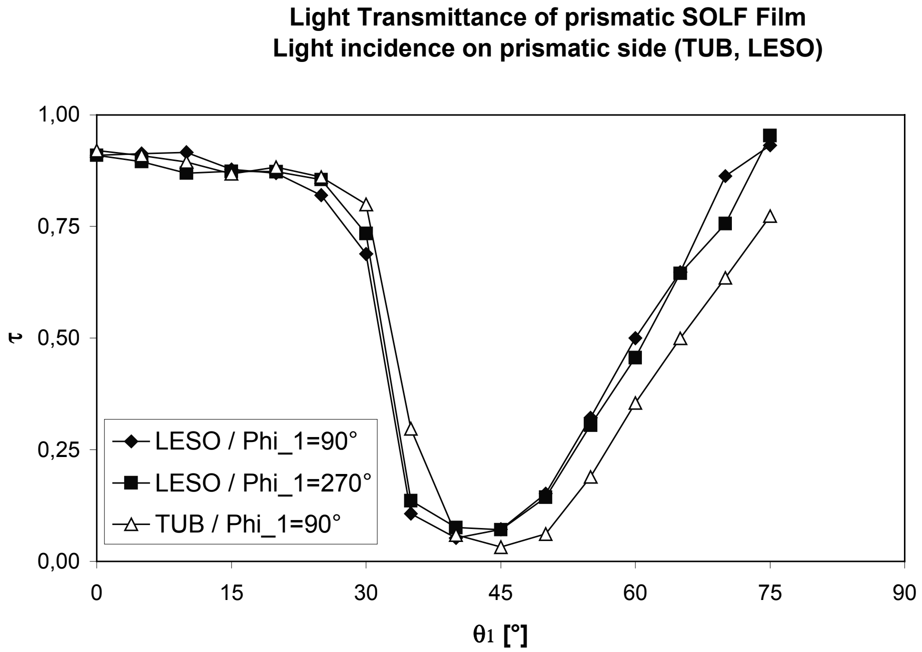

Fig. 9

Considering different parameters affecting the characteristics (see Ch. 2.2) and error sources (see Ch. 4.2.2), the achieved results show a relatively good agreement of the particular values of the light transmittance depending on the light incidence (generally ≤ 5%).

4.2.2 Analysis of Error Sources

In addition to parameters affecting the characteristics (see Ch. 2.2) and the integrating sphere photometer properties (see Ch. 2.5.1), there are error sources due to practical causes. These error sources can be divided into four groups:

- methodical errors
  - integrating sphere photometer
  - goniophotometer

- photometric errors
  - f_1 : V(λ) match
  - f_2 : Cosine response: This error source can cause relatively high deviations especially for regular or nearly regular redirecting systems

- relating to used sphere photometer
  - diameter of the sphere (recommended diameter: D ≥ 0.5 m, better: D ≥ 1 m)
  - diameter of the sample port
  - diameter of the illuminated area of the sample : This is especially important for good diffusing material and for material with a large structure, where the whole structure of the sample has to be covered by the illuminated area.
  - non-uniformity of the reflectance of the inner surface of the sphere : This error source can cause relatively high deviations especially for regular or nearly regular redirecting systems.
  - non-perfect reflecting diffuser of the sphere's inner surface
  - position and size of the baffle inside the sphere between sample port and the detector

- relating to the sample
  - non-uniformity (structure and/or thickness) of the samples
  - adjustment of the sample: This practical error source can cause relatively high deviations especially for materials with high gradients of the characteristics, such as prismatic samples (cf. comparison of results for prismatic SOLF film, light incidence on prismatic side (TUB, LESO))

4.3 Light Transmittance Measurement of Daylighting Systems

Light 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 lot of data has to be stored and, in subsequent steps, presented. A detailed description of the data format and the presentation of the results is given in the following sections.

4.3.1 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 light 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 files 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 light transmittance measurements can be divided into two parts: header section and data section. The header contains basic information about the 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 light transmittance.

In the following lines the beginning of a typical light 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
```

[a.s.o.]

END

4.3.2 Presentation of Measurement Results

Due to the fact, that two parameters are changed during the light transmittance measurements, a lot of data is 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 light transmittance body points out visually angle regions of interest. The following examples show the light transmittance of different daylight elements.

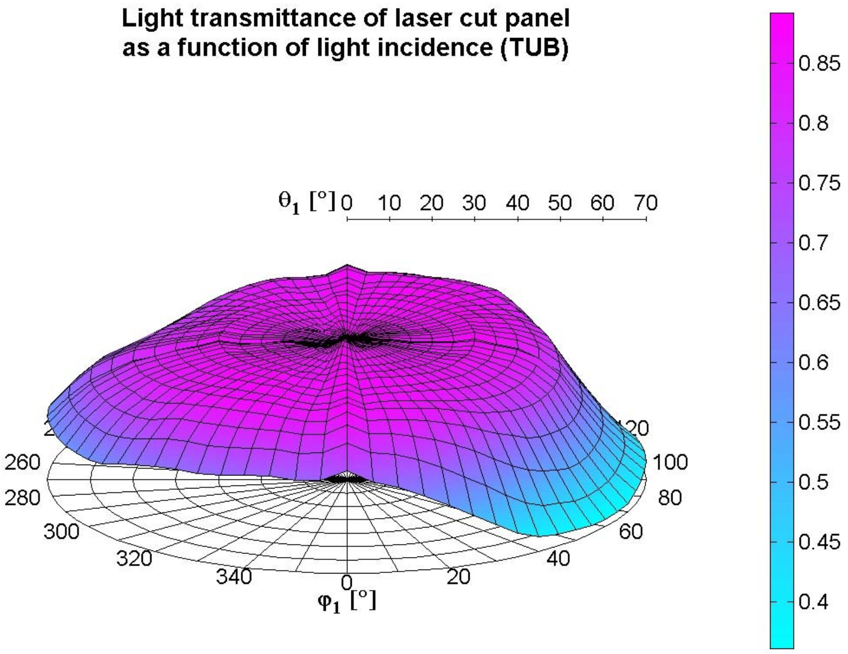

Fig. 10

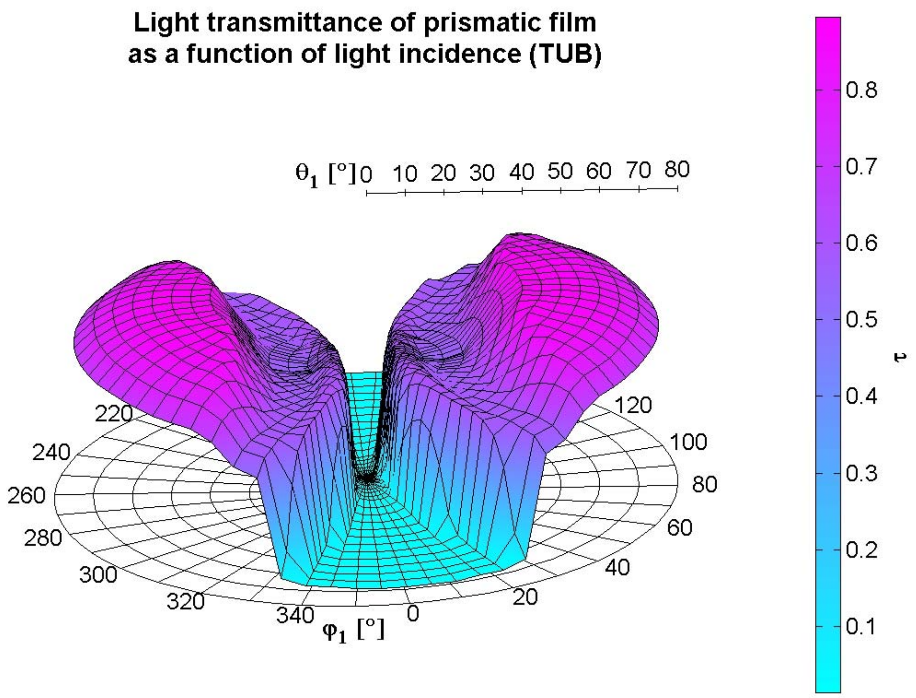
Light transmittance of prismatic film
as a function of light incidence (TUB)
θ1 [°] 0 10 20 30 40 50 60 70 80
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
τ
220
240
260
280
300
320
340
0
20
40
60
80
100
120
φ1 [°]

Fig. 11

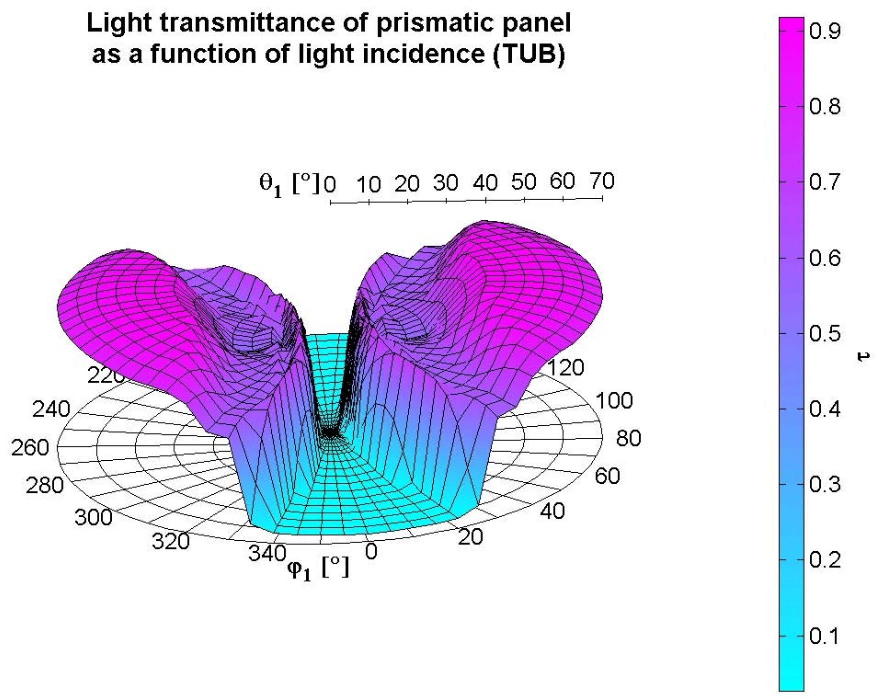
Light transmittance of prismatic panel
as a function of light incidence (TUB)
θ1 [°] 0 10 20 30 40 50 60 70
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
τ
220
240
260
280
300
320
340
0
20
40
60
80
100
120
φ1 [°]

Fig. 12

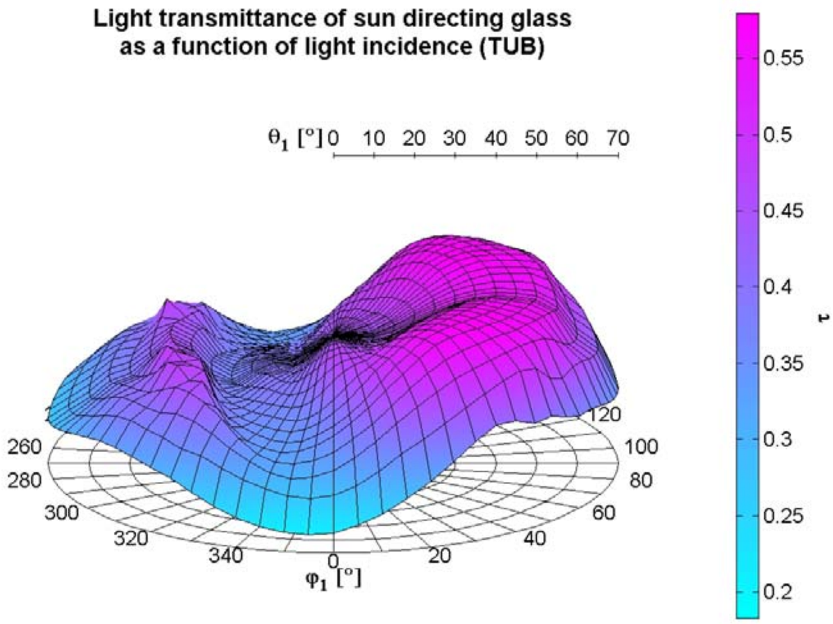
Light transmittance of sun directing glass
as a function of light incidence (TUB)
θ1 [°] 0 10 20 30 40 50 60 70
260
280
300
320
340
0
20
40
60
80
100
120
φ1 [°]
0.55
0.5
0.45
0.4
0.35
0.3
0.25
0.2
τ

Fig. 13

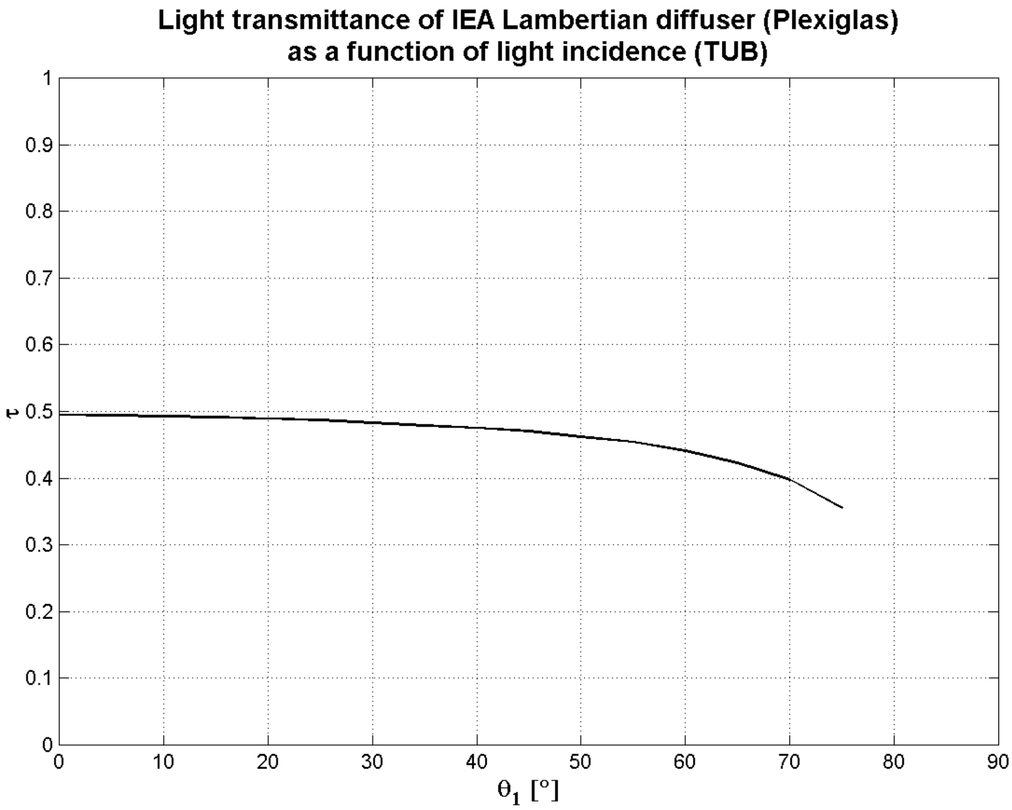
Light transmittance of IEA Lambertian diffuser (Plexiglas)
as a function of light incidence (TUB)
τ
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 10 20 30 40 50 60 70 80 90
θ1 [°]

Fig. 14

Filenames
All the data as well as the presentation of the sample measurements are included on the CD-ROM to this report. All measurements are put to one compressed file ("tub_tau.zip") containing the data files (text files) and one WINWORD document which includes the presentation of the measurement results.

4.3.3 Light Transmittance for Hemispherical Light Incidence

The light transmittance for hemispherical light incidence τ_{dif} is defined as the light 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 light transmittance measurements:

$$\tau_{dif} = \frac{1}{2\pi} \int_{\varphi_1=0}^{2\pi} \int_{\theta_1=0}^{\frac{\pi}{2}} \tau(\varphi_1, \theta_1) \cdot \sin(2\theta_1) \cdot d\theta_1 \cdot d\varphi_1 \qquad (9)$$

For a rotation symmetrical light transmittance:

$$\tau_{dif} = \int_{\theta_1=0}^{\frac{\pi}{2}} \tau(\theta_1) \cdot \sin(2\theta_1) \cdot d\theta_1 \qquad (10)$$

Comparison of values τ_{dif} for hemispherical light incidence

To check the calculated and measured values of light transmittance for hemispherical light incidence, an example is given for plexiglas:

TUB: calculated value acc. to formula (10)	0.45
ISE: measured	0.44

5 BI-DIRECTIONAL MEASUREMENTS

For the bi-directional measurements of selected daylighting systems dependent on light incidence, the following measuring facilities of different institutes are available.

5.1 Description of the Measuring Facilities

5.1.1 Bi-directional Goniophotometer for advanced glazing materials based on digital imaging techniques (EPFL)

Solar Energy and Building Physics Laboratory (LESO-PB)
Swiss Federal Institute of Technology (EPFL)

The goniophotometer is composed of a computer-controlled movable mechanical support, presenting two main rotation axes that are powered by DC motors, using accurate and reliable gear technology (harmonic drivers), and controlled by micro-computer. The light source is placed 6 meters above. It consists of a short-arc discharge lamp (2.5 kW HMI) combining high luminous efficiency (96 Lumen / Watt) with a daylight-close spectrum (5600 K); it is placed in a floodlight projector equipped with a hyperbolic mirrored reflector, Fresnel lens and an optical conic element, to enhance beam uniformity. A high illuminance uniformity is observed on the sample (better than 3%).

There is no movable photometer measuring the transmitted illuminance in each direction, as in the classical goniophotometer conception: instead, a spectrally and photometrically calibrated CCD camera is pointed towards a triangular screen, painted with a spectrally neutral diffusing white paint (LMT photometer paint). The CCD camera (Kappa CF 8/1 DXCair, images of 752 x 582 pixels) proposes computer-selected integration times from 100μs to hours; the lowest integration time used is 40ms, because of light source frequency effects; the diaphragm aperture is fixed manually.

A conic cap is fixed on the main platform (around the camera and the screen) in order to avoid parasitic light; the measurements are performed in a dark room.

Fig. 15: Bi-directional Goniophotometer developed at LESO-PB/EPFL. The CCD camera (absent on the picture) is fixed on the rotating ring at the cross mark.

The rotation of the main platform (θ = 0° to 90°) and the sample holder (ϕ = 0° to 360°) determine the incident direction (see fig. 16); six positions of a 360° rotating ring, moving underneath the main platform (see fig. 15) and on which the camera and the screen are fixed, leads to a representation of the complete transmission hemisphere (see fig. 17), without any inter-reflection. The piloting software allows a fully automated sample characterisation. Only about 2 to 4 minutes are necessary to achieve a set of BTDF data for one incident direction, against hours for classical photogoniometers.

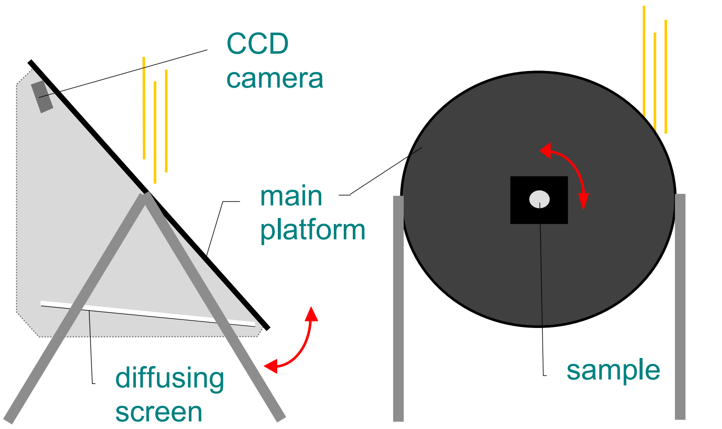

Fig. 16: Rotation of main platform and sample holder

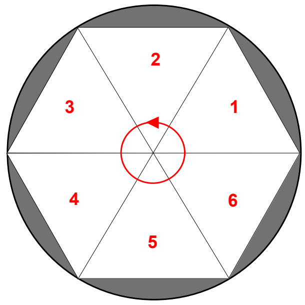

Fig. 17: Rotation of diffusing screen

The sample holder allows free sample sizes, with a maximum size of 40cm x 40cm. A set of diaphragms is used to limit the measured area to 10, 17, 24, and 30cm diameter.

A considered area of 10cm diameter corresponds to a resolution in transmitted directions of 5°; a new calibration of the device could lead to better resolution, with smaller samples, or to lower resolution with bigger samples.

The luminances are measured inside discrete areas on the screen image (216 areas for 5° resolution, see fig. 18), by averaging calibrated pixel values. Saturation and under-exposition effects are avoided by an appropriate and automated selection of integration times, and by an adequate superposition of image parts that present a luminance dynamic adapted to the integration time and the calibration applied.

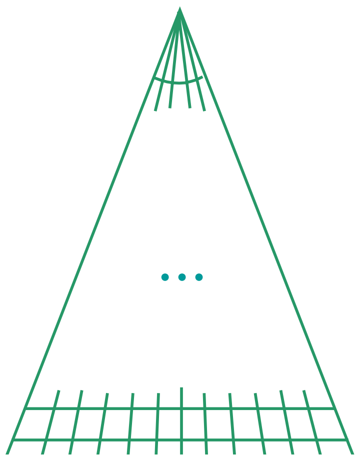

Fig. 18 : Areas delimited by 5° steps in azimuth and altitude

The incident illuminance on the sample plane is measured with an LMT lux-meter. The obtained BTDF "screen" values are mathematically converted into final BTDF (or q) values, coming out from the sample centre.

5.1.2 Designing an apparatus for measuring bi-directional reflection/transmission (ISE)

An apparatus for measuring angle-dependent transmission and reflection of large (40cmx40cm) samples is presented. The apparatus consists of two fixed light sources, an adjustable sample holder and a movable solar cell as the detector. All angle positions are computer-controlled, using a workstation to achieve automatic measurements. The following design features two fixed lamps with a reduced scanning area for the detector as sketched in fig. 19.

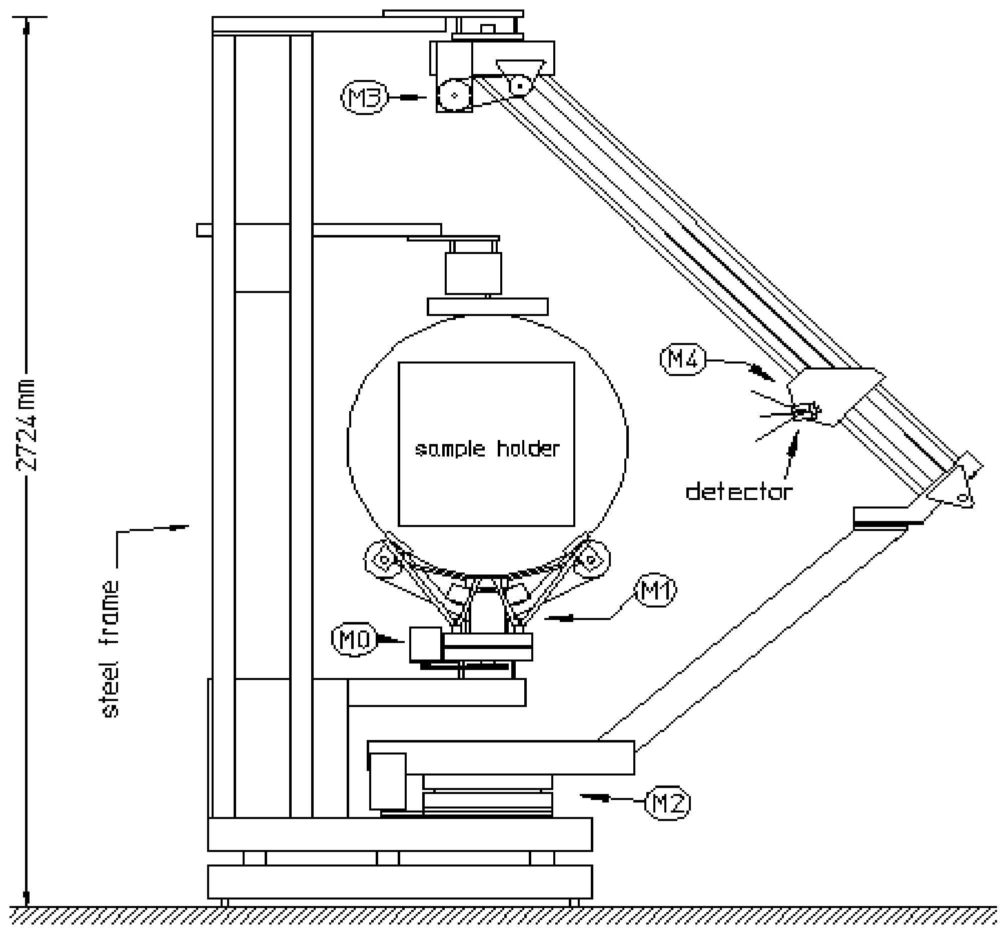

Fig. 19: Schematic side view of the sample holder and detector. M0 to M4 are the stepping motors

Lamps

The ideal lamp should produce parallel, homogeneous illumination across the sample area with a solar-like spectrum. For large samples ($40x40cm^2$) a halogen lamp and a front surface coated, parabolic mirror (lighthouse mirror) was used. Although halogen lamps do not match the solar spectrum well, they are smaller than xenon lamps, have a wider angular output and do not require mechanical shielding. The lamp bulb was mounted in the mirror focus using a steel wire system to minimize shading. To avoid shading completely, an off-axis parabolic mirror could be used. However we estimated that the induced error could be later compensated for by data processing. A battery is used as the power source, providing purely direct current, while an electronic switch (FET) allows computer control.

For transmission measurements on small samples ($4x4cm^2$) a 1kW Xe-lamp produces an 18mm diameter beam, using a 0.8mm pinhole and a photographic lens (f=125mm) to provide a parallel beam with a Gaussian cross-section. The light intensity is stabilized by a photodetector and feedback circuits to the power source. A mechanical shutter allows control by the host computer.

Sample holder

The sample has to be turned around two orthogonal axes, one perpendicular to the incident beam. In this set-up the first axis is mounted vertically for mechanical reasons. The second axis could either be parallel to the sample surface or perpendicular to it: the latter avoids shadows cast by the mechanical hinge on the sample. The sample holder consists of an 800mm diameter aluminium disc, 5mm thick, with a $500x500mm^2$ hole at the center. T-shape aluminium mouldings are mounted around the square hole, giving mechanical stiffness and a mounting frame for the inner sample holders. Various sample sizes and shapes have their own “inner” custom mounting.

Detector

The apparatus uses a $2x2cm^2$ solar cell as a detector; its short-circuit current is measured with a Keithley 485 Picoammeter. Since most measured results are used for daylighting and photometric simulations, a green V(l) filter adapts the spectral sensitivity to the photopic response. The acceptance angle of the detector is designed for full view of a $40x40cm^2$ sample (maximum 39°).

5.1.3 Short Description of the Spiral Goniophotometer for Bi-directional Measurements (TUB)

Principle :
An hemispherical surface with a radius of 2 m is scanned in a spiral form by rotating the sample and the light source holder around a vertical axis and simultaneously swiveling the detector on a horizontal axis (viewing angles φ_2 and θ_2).

Detector :
- photoelement with V(λ)- and cos – evaluation

Light source :
- incandescent lamp (100 W, 12 V) with optic
- illuminated area on samples with a diameter of 7 cm

Adjustment of the light incidence angles φ_1 and θ_1 : manually

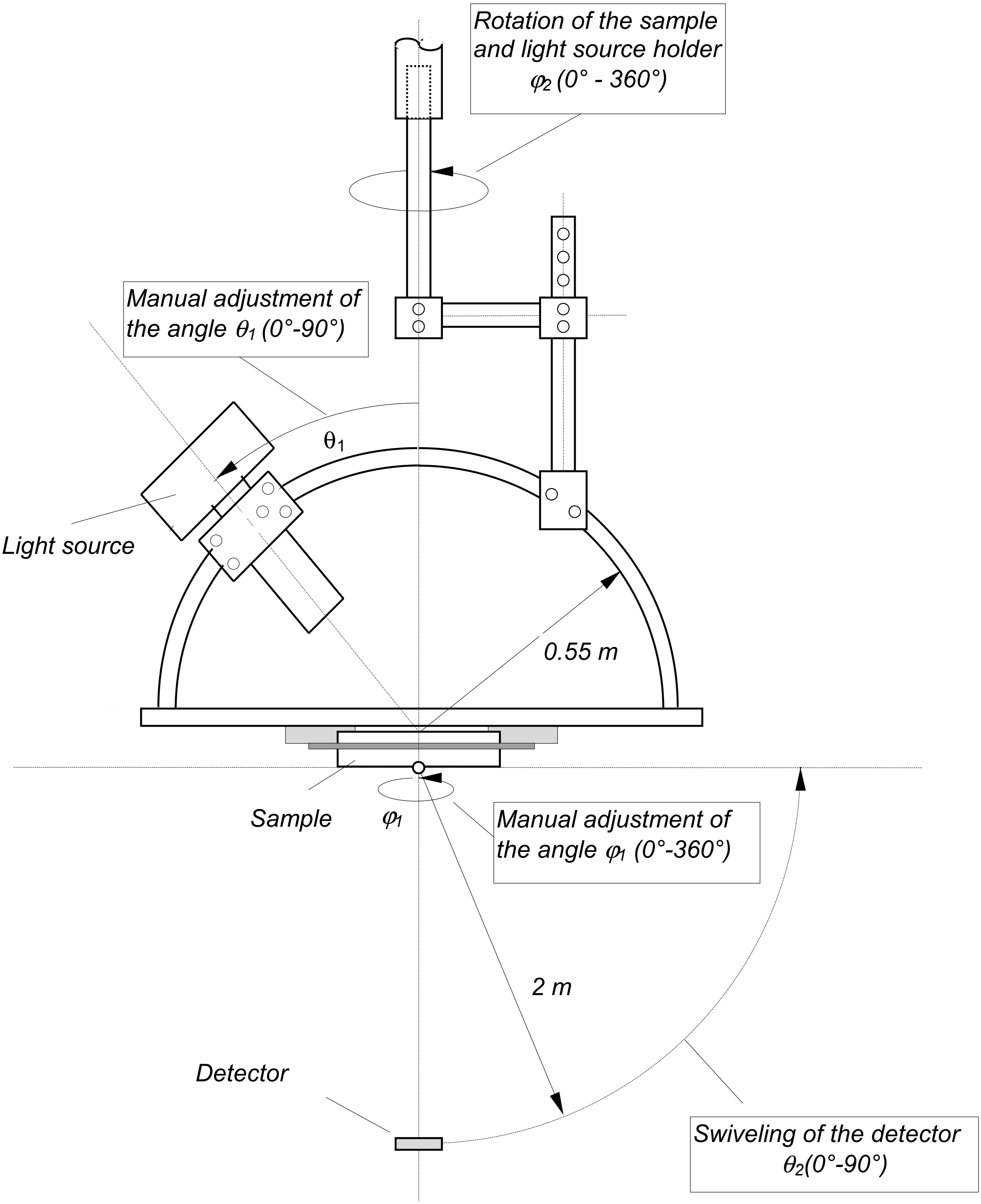

Fig. 20: Side view of the spiral goniophotometer

Light incidence : angles θ_1 und φ_1

Viewing : angles θ_2 und φ_2

5.2 Pilot Measurements

In order to be able to compare the measurements of the different institutes, two optical elements have been chosen for pilot measurements: a prismatic film from 3M (SOLF) and a Lambertian diffuser (Plexiglas). The samples were sent to the according institutes by ILB. Due to very high gradients in the bi-directional values of the 3M-Solf film, the comparison of the measurement results for this sample was later cancelled.

5.2.1 Comparison of Measuring Results

The pilot measurements for plexiglas were carried out by ISE, TUB and EPFL. Some examples are given below:

ISE Plexiglas light incidence θ_1=0°

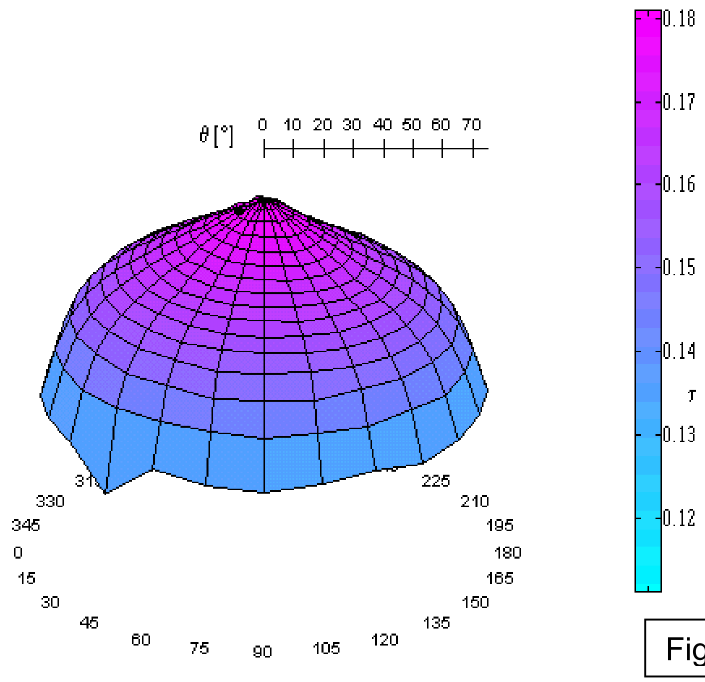

Fig. 21

ISE Plexiglas light incidence θ_1=30°

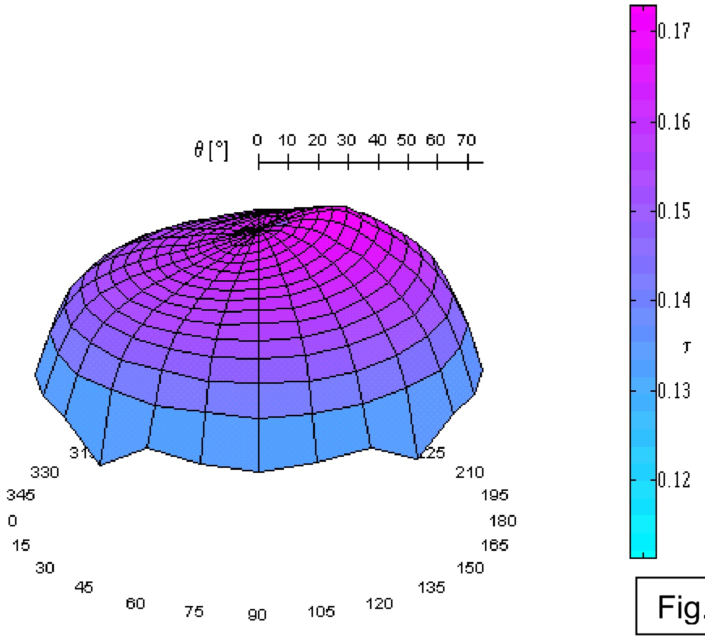

Fig. 22

ISE Plexiglas light incidence θ_1=50°

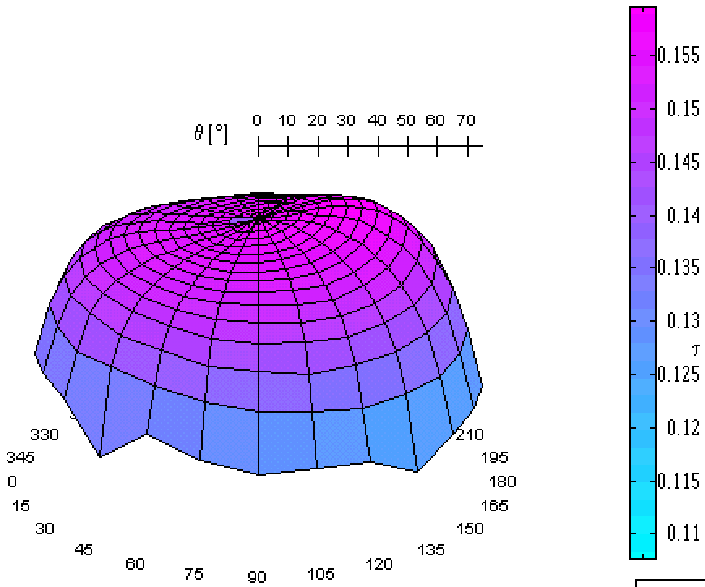

Fig. 23

TUB Plexiglas light incidence θ_1=0°

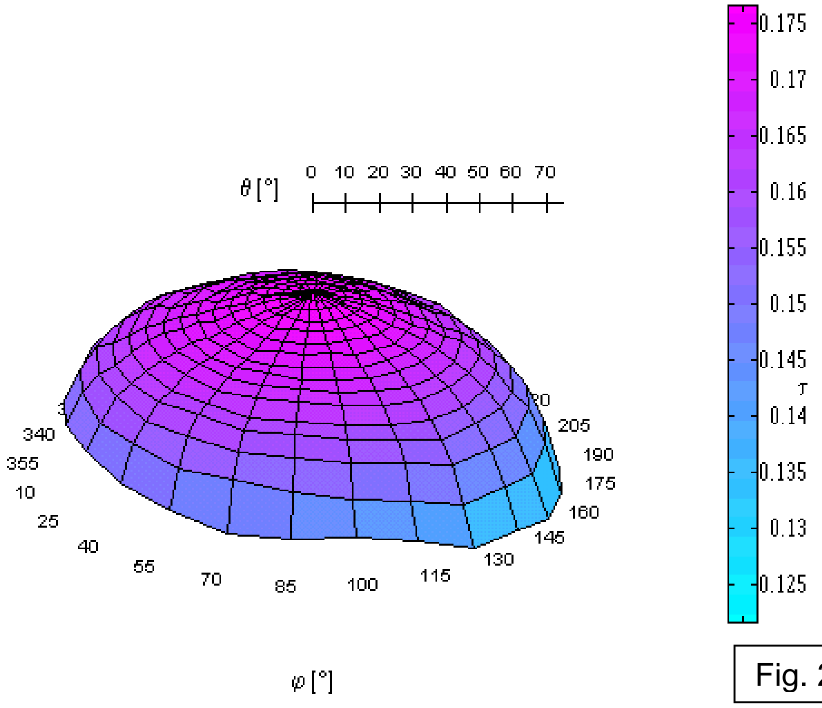

Fig. 24

TUB Plexiglas light incidence θ_1=30°

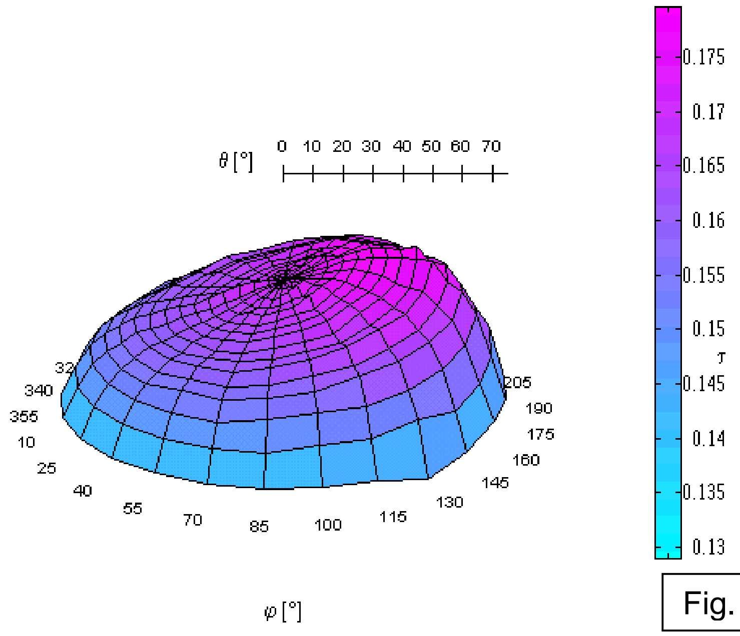

Fig. 25

TUB Plexiglas light incidence θ_1=50°

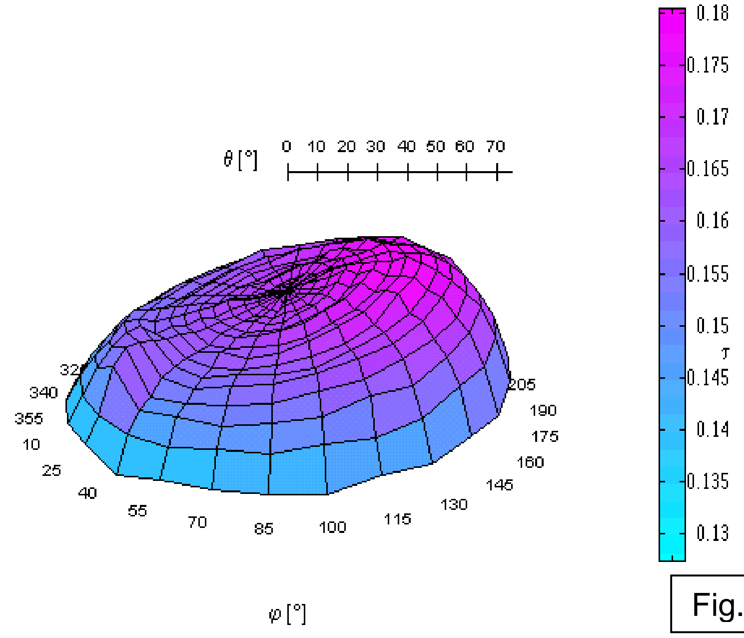

Fig. 26

EPFL Plexiglas light incidence θ_1=0°

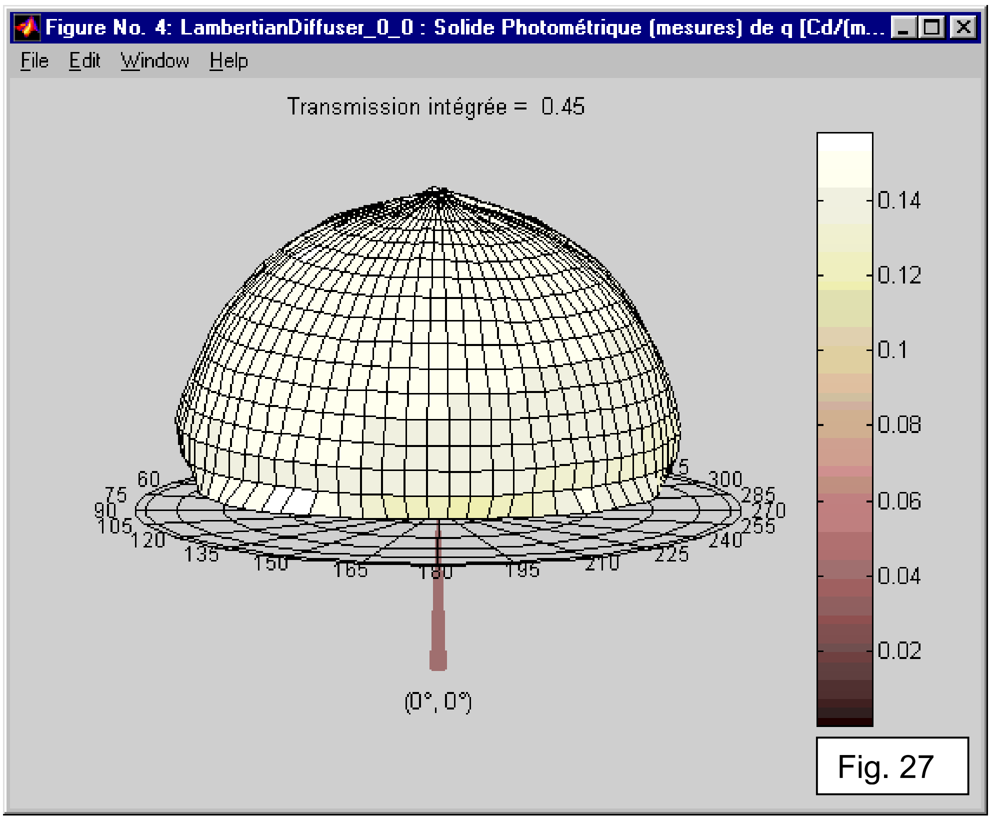

Fig. 27

EPFL Plexiglas light incidence θ_1=40°

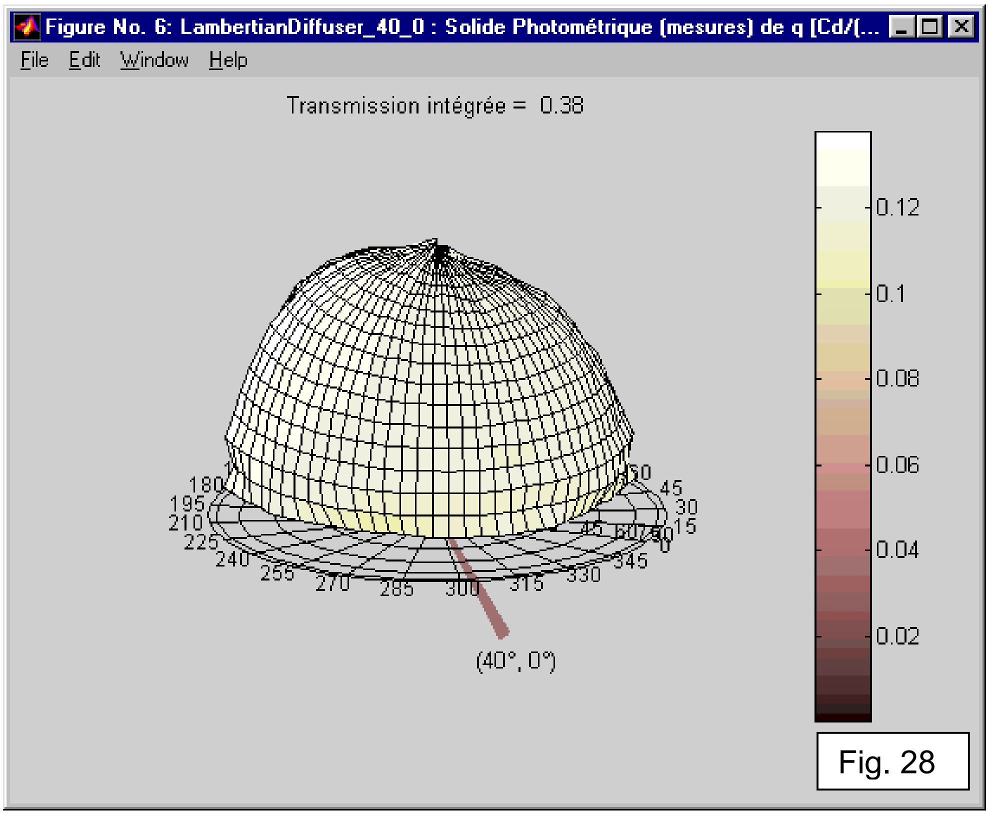

Fig. 28

Comparisons

In the following, the deviations (in %) of the interpolated BTDF values of plexiglas (measured by ISE and TUB) for different light incidences are shown:

Light incidence θ_1=0°

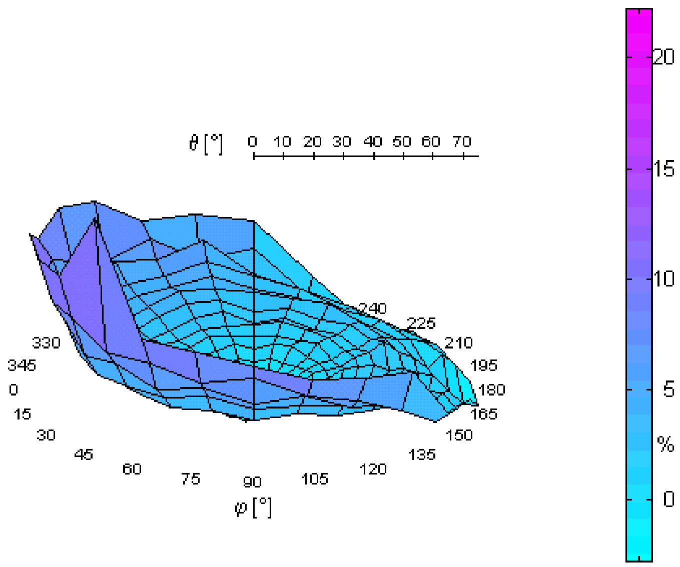

Fig. 29

Light incidence θ_1=30°

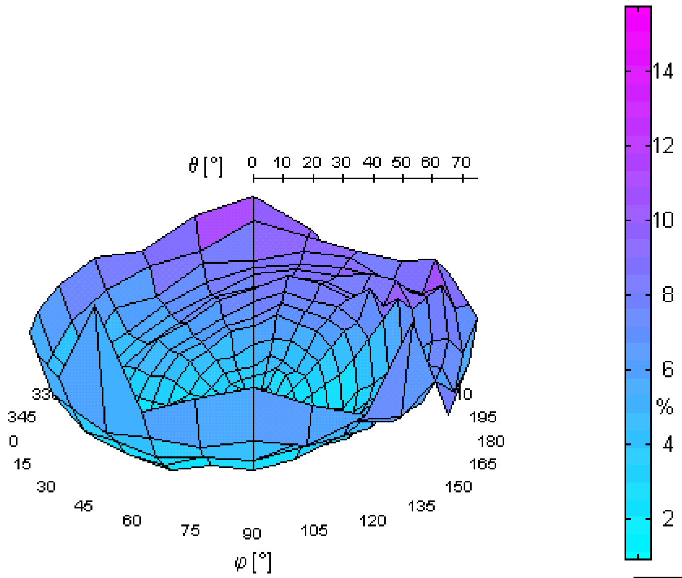

Fig. 30

Light incidence θ_1=50°

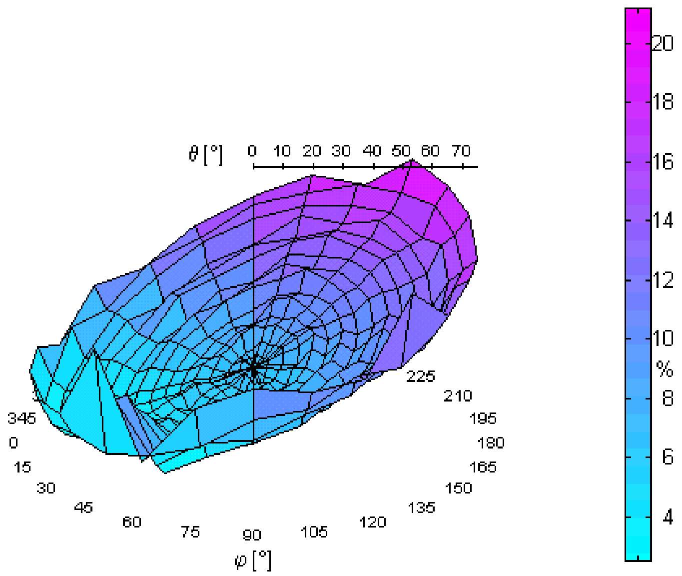

Fig. 31

Considering different parameters affecting the characteristics (see Ch. 2.2) and error sources (see ch. 5.2.2), the achieved results show a relatively good agreement of the particular values of the bi-directional results (generally ≤10°).

5.2.2 Analysis of Error Sources

In addition to the parameters affecting the characteristics (see Ch. 2.2) and the properties of the used goniophotometers (see Ch. 5.1), there are error sources due to practical causes. These error sources can be divided into four groups:

- methodical errors
  - goniophotometer with V(λ) photometer head: For this type of goniophotometers, the illuminance L is determined from the measured illuminance **E´** at the viewing point as $\mathbf{L = E' \,.\, r^2 \;/\; \{E \,.\, (A \,.\, \cos \theta_2)\}}$; **r** is the distance between the photometer head and sample; $\mathbf{(A \,.\, \cos \theta_2)}$ is the illuminated sample surface projection from the viewing point. In this case, the validity of the critical photometric distance is assumed. As a rule of thumb, the measuring distance should be at least ten times the diameter of the illuminated sample area. In addition to that, it is influenced by the form of the sample's light distribution; i.e. for a peaked light distribution, the distance must be much longer (e.g. for a spotlight).
  - goniophotometer with CCD camera: For such goniophotometers, there is not enough experience at the present time.

- photometric errors
  - f_1 : V(λ) match

- relating to the used goniophotometers: These error sources can depend very much on the mechanical and photometrical construction of the photometer. Errors that occur very often are:
  - diameter of the illuminated area of the sample : This is especially important for good diffusing material and for material with a large structure, where the whole structure of the sample has to be covered by the illuminated area.
  - stray light:

- relating to the sample
  - non-uniformity (structure and/or thickness) of the samples
  - adjustment of the sample: This practical error source can cause relatively high deviations especially for materials with high gradients of the characteristics, such as prismatic samples (cf. comparison of results for prismatic SOLF film, light incidence on prismatic side (TUB, LESO))

5.3 Bidirectional Measurement of Daylighting Systems

In contrast to light 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 light transmittance measurements.

$$\tau(\varphi_1,\theta_1)=\frac{1}{2}\int_{\varphi_2=0}^{2\pi}\int_{\theta_2=0}^{\frac{\pi}{2}} q(\varphi_2,\theta_2)\cdot\sin(2\theta_2)\cdot d\theta_2\cdot d\varphi_2 \qquad (11)$$

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

5.3.1 Light Incidence and Data Format

It is agreed upon to limit the angles of light incidence according to the sky luminance distribution by Tregenza [14]. This leads to 145 different light incidence directions which are shown in the figure and the table below.

Table 1: Light Incidents 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 θ_1 = 0°, 12°, 24°, 36°, 48°, 60°, 72° and 84° need to be done.

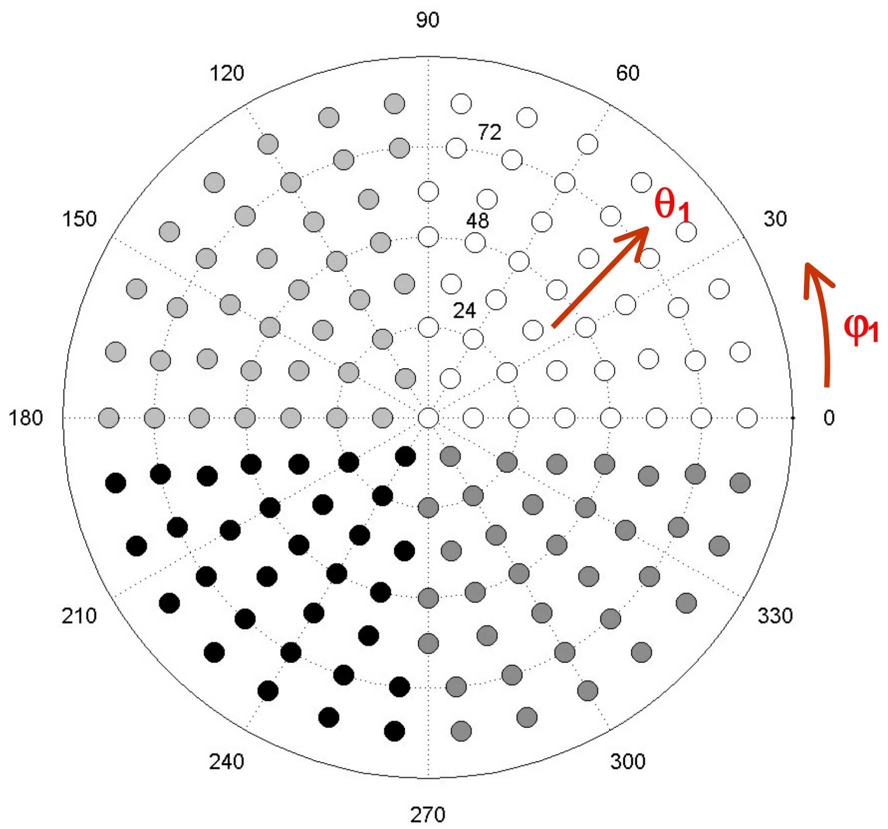

Fig. 32: Light Incidents for Bi-directional Measurements

Data Format

In order to store the measurement results, all the aspects of the data format for light transmittance measurements need to be taken into account (see also 4.2.1 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 more easy. 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 4.3.1 Light Incidence). In order to minimize the disk space for the file without loosing 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
[a.s.o.]
END
```

5.3.2 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 co-ordinates 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, 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 report. All the files necessary to characterize a sample are put together in a compressed file. For each light incidence there is one text file. The presentation of the measurement results is put to a WINWORD document file.
E.g. the filename "ise_3m_36_40.txt" contains the measurement results of the 3M-optical lighting film, that were done at ISE. The light incidence was: θ_1 = 36° and φ_1 = 40°. The corresponding presentation of this data can be found in the file "ise_3m.doc" (all the files of this example are included in "ise_3m.zip").

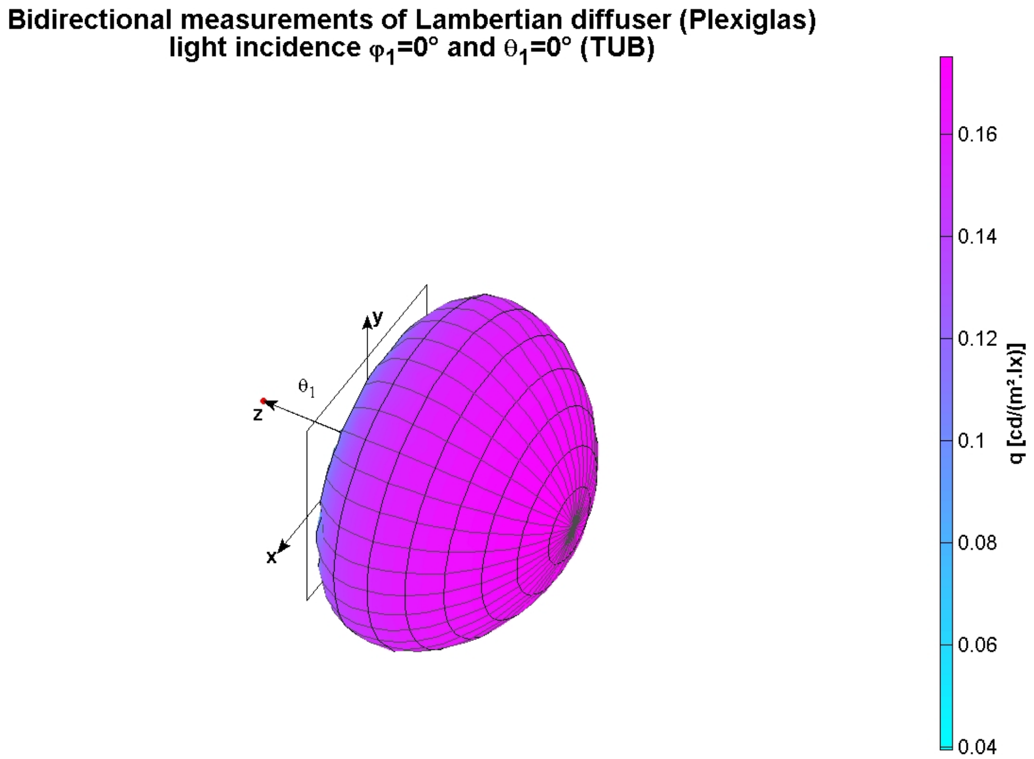

Fig. 33

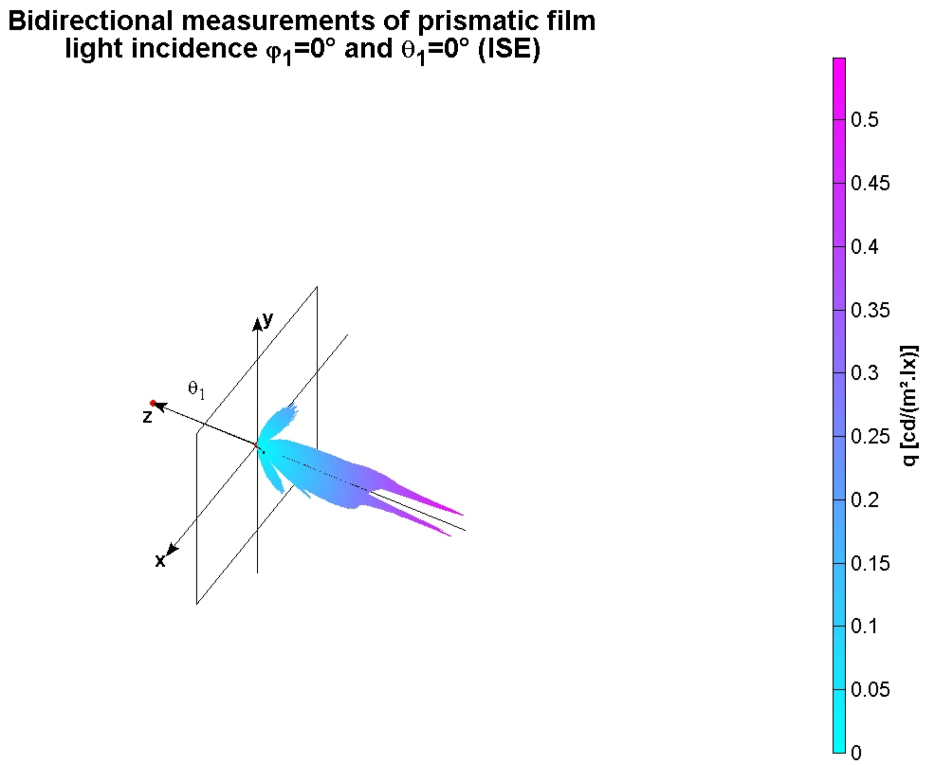
Bidirectional measurements of prismatic film
light incidence φ1=0° and θ1=0° (ISE)
y
z
x
θ1
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
q [cd/(m².lx)]

Fig. 34

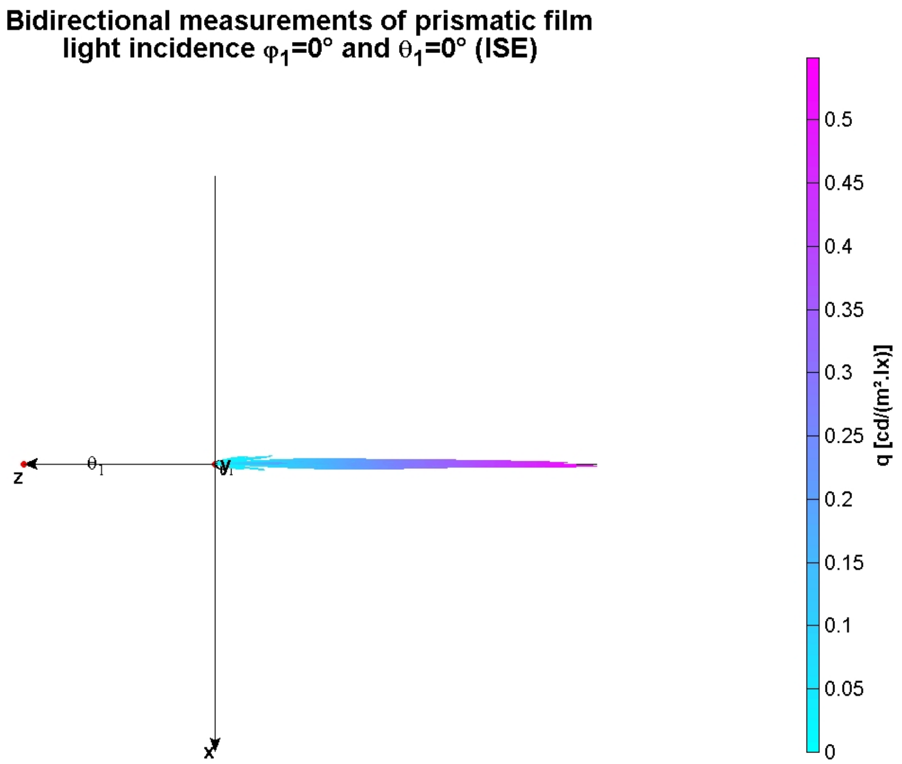
Bidirectional measurements of prismatic film
light incidence φ1=0° and θ1=0° (ISE)
z
x
θ1
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
q [cd/(m².lx)]

Fig. 35

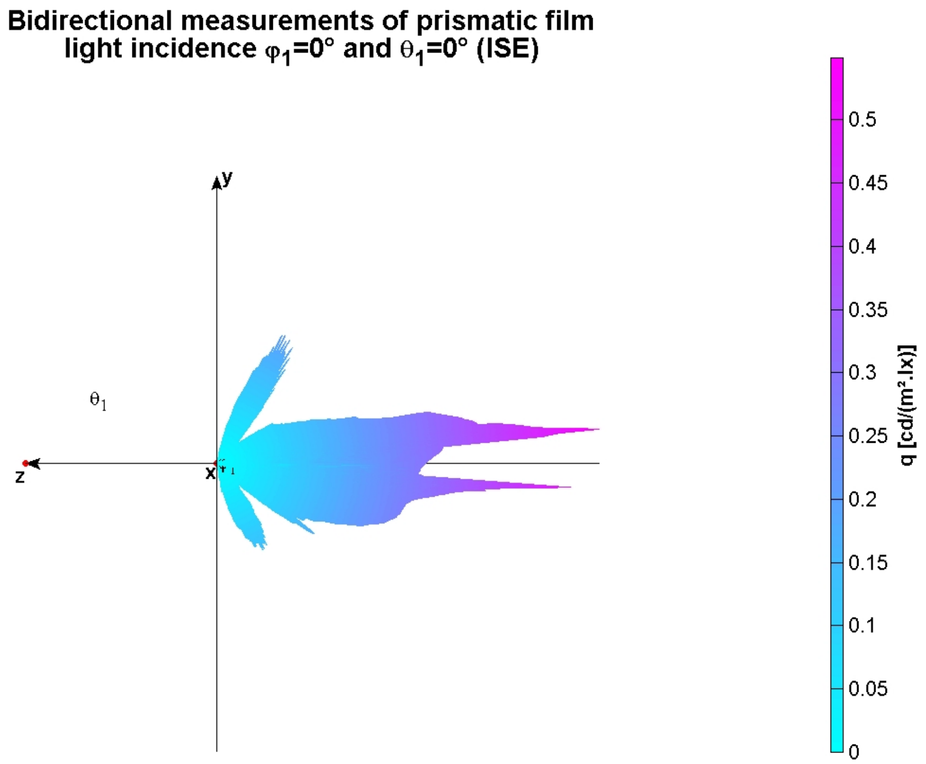
Bidirectional measurements of prismatic film
light incidence φ1=0° and θ1=0° (ISE)
y
θ1
z
x
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
q [cd/(m².lx)]

Fig. 36

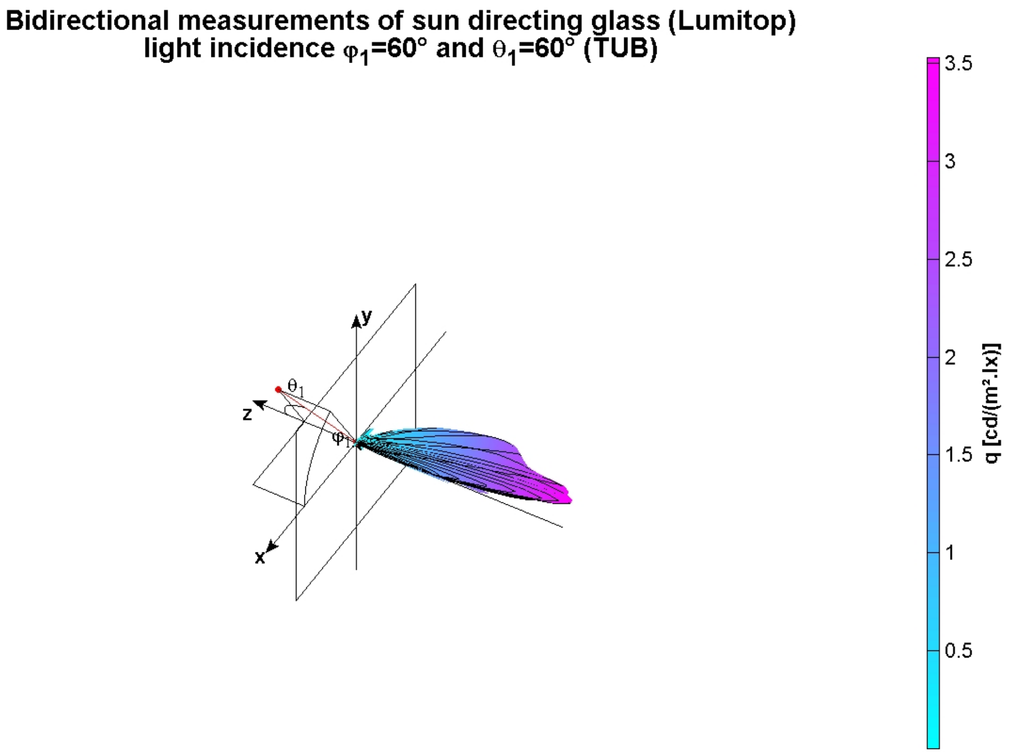
Bidirectional measurements of sun directing glass (Lumitop)
light incidence φ1=60° and θ1=60° (TUB)
y
z
x
θ1
φ1
3.5
3
2.5
2
1.5
1
0.5
q [cd/(m².lx)]

Fig. 37

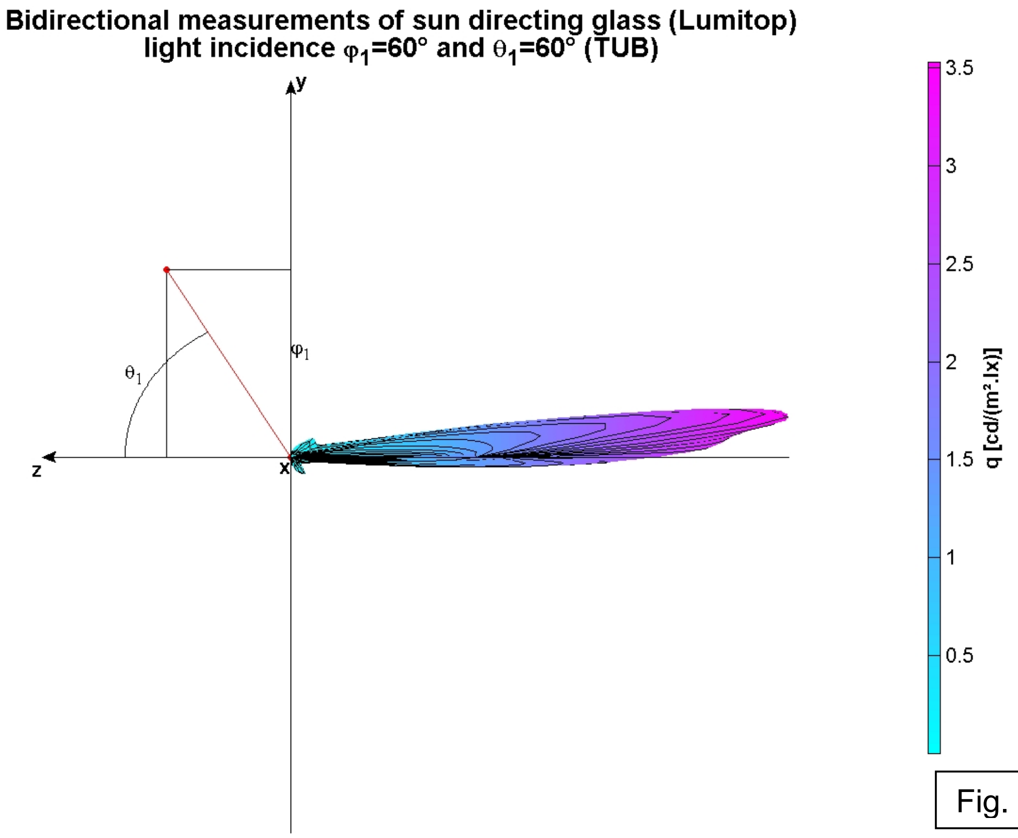
Bidirectional measurements of sun directing glass (Lumitop)
light incidence φ1=60° and θ1=60° (TUB)
y
z
x
θ1
φ1
3.5
3
2.5
2
1.5
1
0.5
q [cd/(m².lx)]

Fig. 38

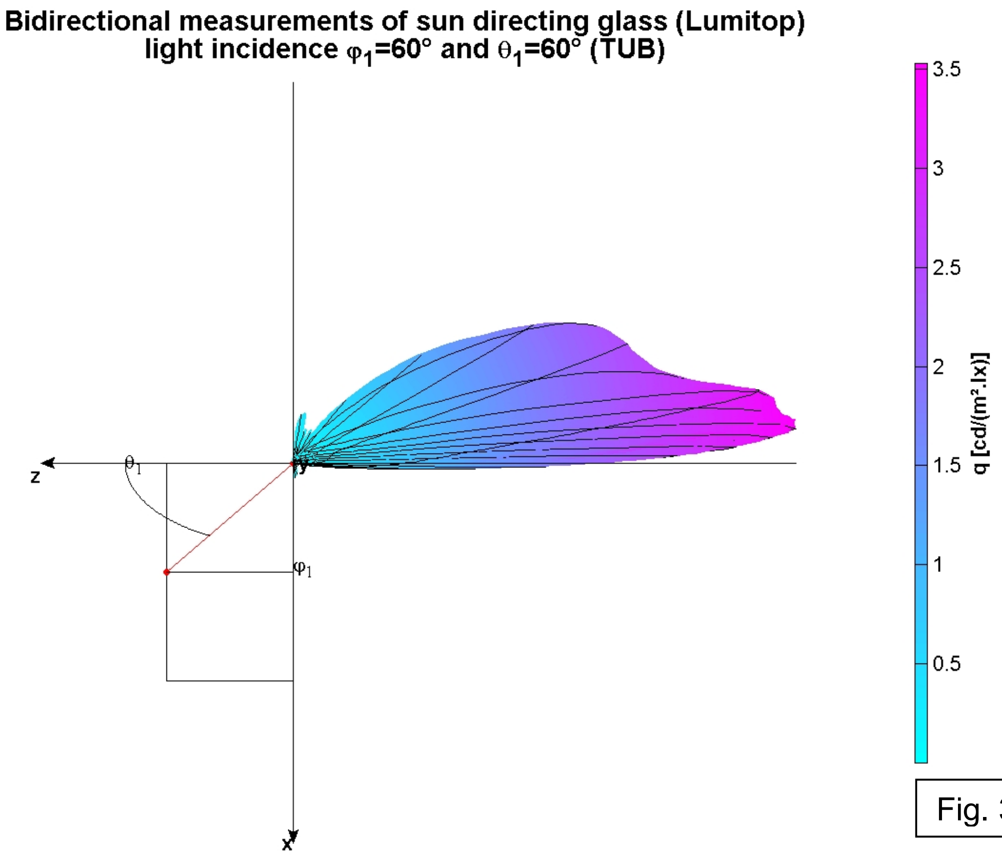
Bidirectional measurements of sun directing glass (Lumitop)
light incidence φ1=60° and θ1=60° (TUB)
z
θ1
y
φ1
x
3.5
3
2.5
2
1.5
1
0.5
q [cd/(m².lx)]

Fig. 39

6 REFERENCES

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8 IEA INFORMATION

INTERNATIONAL ENERGY AGENCY

The International Energy Agency (IEA) was established in 1974 as an autonomous agency within the framework of the Economic Cooperation and Development (OECD) to carry out a comprehensive program of energy cooperation among its 25 member countries and the Commission of the European Communities.

An important part of the Agency's program involves collaboration in the research, development and demonstration of new energy technologies to reduce excessive reliance on imported oil, increase long-term energy security and reduce greenhouse gas emissions. The IEA's R&D activities are headed by the Committee on Energy Research and Technology (CERT) and supported by a small Secretariat staff, headquartered in Paris. In addition, three Working Parties are charged with monitoring the various collaborative energy agreements, identifying new areas for cooperation and advising the CERT on policy matters.

Collaborative programs in the various energy technology areas are conducted under Implementing Agreements, which are signed by contracting parties (government agencies or entities designated by them). There are currently 40 Implementing Agreements covering fossil fuel technologies, renewable energy technologies, efficient energy end-use technologies, nuclear fusion science and technology, and energy technology information centers.

IEA SOLAR HEATING AND COOLING PROGRAMME

The Solar Heating and Cooling Programme was one of the first IEA Implementing Agreements to be established. Since 1977, its 21 members have been collaborating to advance active solar, passive solar and photovoltaic technologies and their application in buildings.

Australia	Finland	Norway
Austria	France	Portugal
Belgium	Italy	Spain
Canada	Japan	Sweden
Denmark	Mexico	Switzerland
European Commission	Netherlands	United Kingdom
Germany	New Zealand	United States

A total of 30 Tasks have been initiated, 20 of which have been completed. Each Task is managed by an Operating Agent from one of the participating countries. Overall control of the program rests with an Executive Committee comprised of one representative from each contracting party to the Implementing Agreement. In addition, a number of special ad hoc activities--working groups, conferences and workshops--have been organized.

The Tasks of the IEA Solar Heating and Cooling Programme, both completed and current, are as follows:

Completed Tasks:

Task 1	*Investigation of the Performance of Solar Heating and Cooling Systems*
Task 2	*Coordination of Solar Heating and Cooling R&D*
Task 3	*Performance Testing of Solar Collectors*
Task 4	*Development of an Insolation Handbook and Instrument Package*
Task 5	*Use of Existing Meteorological Information for Solar Energy Application*
Task 6	*Performance of Solar Systems Using Evacuated Collectors*
Task 7	*Central Solar Heating Plants with Seasonal Storage*
Task 8	*Passive and Hybrid Solar Low Energy Buildings*
Task 9	*Solar Radiation and Pyranometry Studies*
Task 10	*Solar Materials R&D*
Task 11	*Passive and Hybrid Solar Commercial Buildings*
Task 12	*Building Energy Analysis and Design Tools for Solar Applications*
Task 13	*Advance Solar Low Energy Buildings*
Task 14	*Advance Active Solar Energy Systems*
Task 16	*Photovoltaics in Buildings*
Task 17	*Measuring and Modeling Spectral Radiation*
Task 18	*Advanced Glazing and Associated Materials for Solar and Building Applications*
Task 19	*Solar Air Systems*
Task 20	*Solar Energy in Building Renovation*
Task 21	*Daylight in Buildings*

Completed Working Groups:

CSHPSS
ISOLDE
Materials in Solar Thermal Collectors
Evaluation of Task 13 Houses

Current Tasks:

Task 22	*Building Energy Analysis Tools*
Task 23	*Optimization of Solar Energy Use in Large Buildings*
Task 24	*Solar Procurement*
Task 25	*Solar Assisted Air Conditioning of Buildings*
Task 26	*Solar Combisystems*
Task 27	*Performance of Solar Facade Components*
Task 28	*Solar Sustainable Housing*
Task 29	*Solar Crop Drying*
Task 30	*Solar City (Task Definition Phase)*
Task 31	*Daylighting Buildings in the 21st Century*

Current Working Groups:

PV/Thermal Systems (Definition Phase)

To receive a publications catalogue or learn more about the IEA Solar Heating and Cooling Programme visit our Internet site at **http://www.iea-shc.org** or contact the SHC Executive Secretary, Pamela Murphy, Morse Associates Inc., 1808 Corcoran Street, NW, Washington, DC 20009, USA, Tel: +1/202/483-2393, Fax: +1/202/265-2248, E-mail: pmurphy@MorseAssociatesInc.com.