Lecture

Permanent Daylight Measurement

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Daylighting is important for interior and public lighting with respect to energy saving for electric lighting. Our knowlege of daylight data is limited. Therefore, the CIE started an International Daylight Measuring Year (IDMY) to state long term average daylight data. This paper reports on the development of special instrumentation for this purpose.

1. Introuduction

The main purpose of windows is the possibility of the view out, which cannot be replaced by other technical means. A minimum window area is necessary for this, which is not influenced by the daylight level[1].

Beside this, the daylighting of interiors is a very important factor, because it can give effective results in energy saving. Less artificial light lowers the operating cost of an illuminating installation and those for coding. But this must be checked in advance, and therefore a prediction of inside available daylight, the locally available level, and statistical distribution of outside daylight quantities have to be known.

Other fields of interest to know these data are museum lighting (degradation of materials) and photovoltaic use of energy and many more.

2. Quantities to be measured

The main research problem is to find the correlation of the main daylight quantities and the local long time average conditions.

Therefore, it is proposed to make long time measurements of:

- global horizontal illuminance
- global vertical illuminance in N-S-E-W direction
- zenith sky luminance
- sky luminance. distribution
- direct sun illuminance
- diffuse horizontlal illuminance
- cloudiness
- sunshine duration

These data are not sufficiently known, therefore, the CIE starts the IDMY[2]. For heating and cooling load the radiant data must also be known, as there are:

- global irradiance, horizontal and vertical
- diffuse horizontal irradiance
- direct solar irradiance
- measurements of the spectral power distribution and the luminous color of the different daylight phases are necessary, too.

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The turbitidy of the atmoshpere can be calculated from direct sun illuminance, respectively irradiance. The measurement of reflectance ρ_{dif} of ground and obstruction at the measuring stations might be necessary, too. For the inside daylight prediction the characteristics of glazings must be known, for inside daylight control a daylight factot meter is necessary.

3. Characteristics of daylight illuminance meters

The quality of illuminance meters can be described by errors in respect to different parameters[3]. Some of them and some additional parameters are important, also for daylight measuring equipment:

Parameter	Error limit	
$-V(\lambda)$-match	f_1	$< 2.5\%$
$-U_V$-response	u	< 0.2
$-$IR-response	r	< 0.2
$-$cos-response	f_2	$< 1.5\%$
$-$linearity error	f_3	$< 0.2\%$
$-$error of display unit	f_4	$< 0.2\%$
$-$fatigue at 10 Klx	f_5	$< 0.1\%$
$-$settling time	t_{max}	< 0.1s
$-$error of range change	f_{11}	$< 0.1\%$
$-$temperature coefficient	α	$< 0.1\%/$K

other characteristics are

- zero setting drift
- mechanical stability
- climatic stability
- recalibration period

4. Photometer heads for illuminance

In the daylight photometer heads for daylight measurements the $V(\lambda)$ matched photovoltaic cells are arranged splash water proof under a glass dome and are thermostated. Thus correct measurement results are obtained within a wide ambient temperature range.

The daylight photometer heads are accomodated in a splash proof housing covered by a fiber glass shield. This prevents the housing getting heated up by solar radiation. The air between housing and shield is ventilated periodically by means of a fan. For low ambient temperature the housing is heated.

The cosine corrected $V(\lambda)$-detector is set in an aluminium block which is kept on a constant temperature (35°C) using a thermoeletric cooler. In combination with a special electronic circuit this device has the ability in cooling or heating the block to the desired temperature. The detector is hermetically sealed by a glass dome.

Pipes connect the hollow space under the dome with the heremtically sealed inside of the main body. By means of silicagel the inside air is kept dry and is in continuous circulation in order to prevent the greenhouse effect under the glass dome. The complete unit is mounted on an adjustable table which allows precise horizontal allignment. The table can be screwed to the ground.

The built-in sensors are precise detectors for photometry. The relative spectral responsivity $s(\lambda)_{rel}$ of these heads are matched to the function of relative spectral responsivity $V(\lambda)$ of the human eye. This is done under strict observance of the respective recommendations[3, 15].

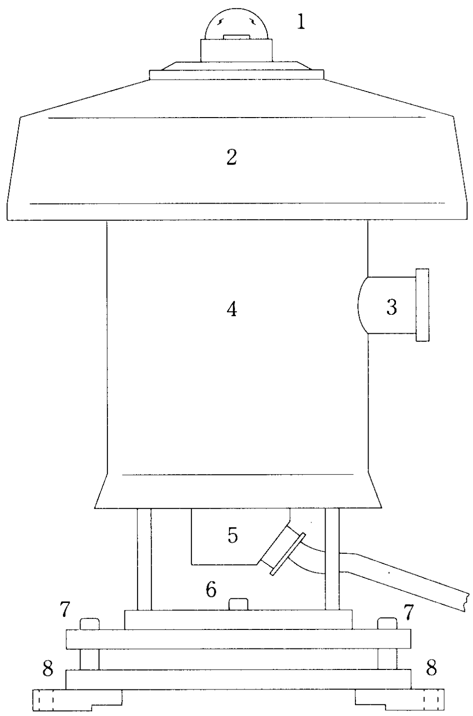

Figure 1 Daylight Photometer Head for horizontal illuminance, schematic drawing

1 $V(\lambda)$-detector with glass dome
2 Top cover (hiding fan and thermoelectric cooler for the thermostatisation)
3 Silicagel cartridge for keeping the inside main body absolutely dry
4 Cover of main body
5 Waterproof heavy duty connectors
6 Adjustment factility for directional alignment
7 Base plate with an adjsutment facility for horizontal alignment
8 Table with mounting possibility

4.1 Global horizontal and vertical illuminances

The Daylight Photometer Head with 5 $V(\lambda)$ detectors arranged horizontally and vertically in north, east, south, west direction is additionally equipped with a shading ring. It serves for shading the ground in such a way that no reflected light can disturb the measurement of the vertically arranged detectors. The upper edge of the shading ring is on the same level as the middle of the light acceptance area of those detectors (Figure 2).

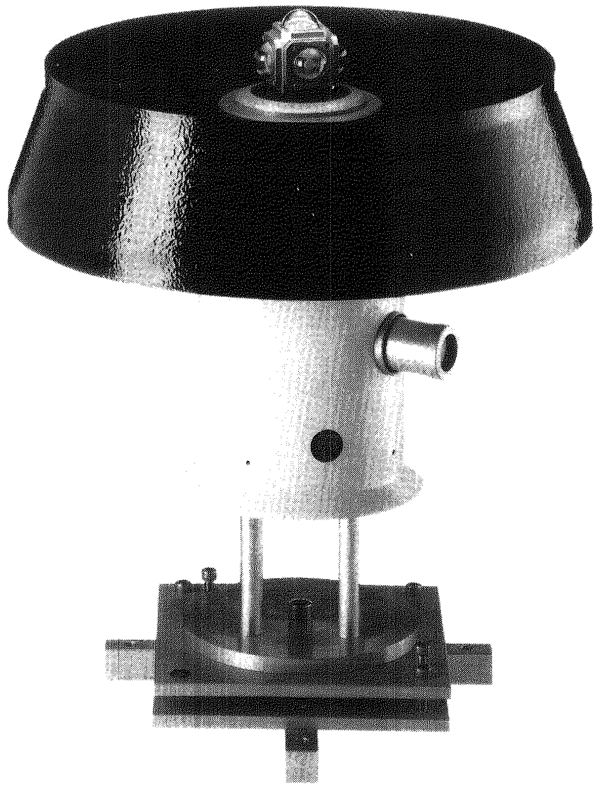

Figure 2 Daylight photometer Head

4.2 Diffuse horizontal illuminance

The Diffuse Horizontal Illuminance Meter is additionally equipped with an adjustable shadow ring avoiding direct sunlight on the detector surface. By this, only diffuse hemispherical skylight can be measured. The ring with a special profile has a nearly constant view angle during the year and guarantees stability even at high winds (Figure 3).

4.3 Direct illuminance with a sun tracker

The photometer head for direct (sun) illuminance has baically the same construction as the above mentioned ones, but uses a tubr to screen the diffuse sky light. It needs additionally a mechanical turning equipment in order to follow the sun. For this, the Sun Tracker for permanent outdoor use with two motor driven axes was developped. It has the capability to carry the Daylight Photometer Head and a radiomenter head with tube for direct sun illuminance/irradiance measurement and can be equipped with two additional sensors for diffuse illuminance and irradiance quantities.

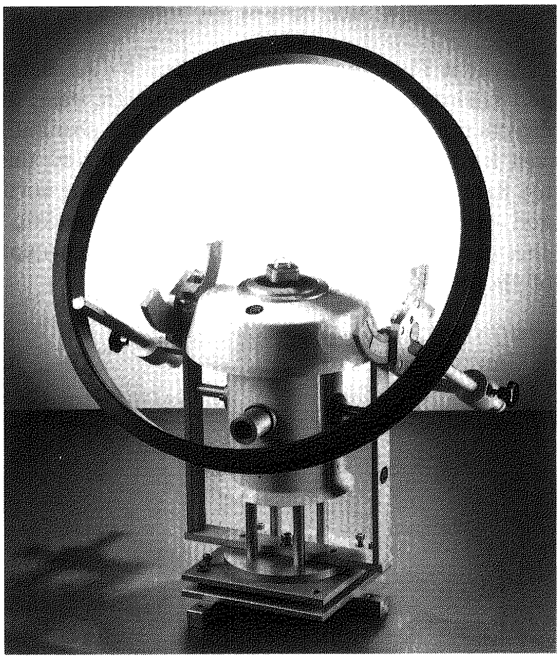

Figure 3 The shadow ring for diffuse horizontal illuminace measurement

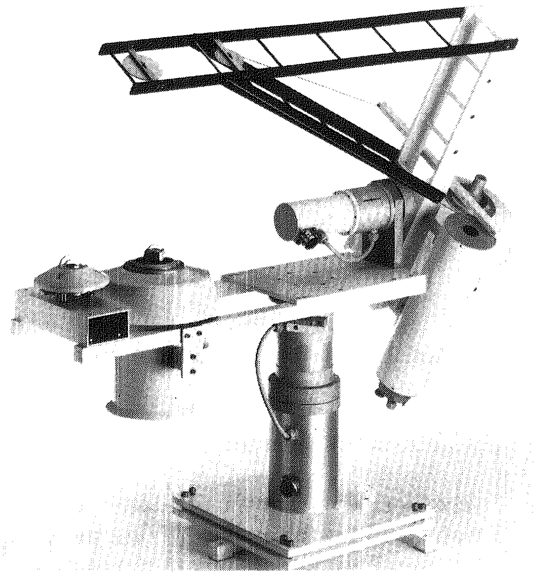

Figure 4 Sun Tracker equipped with scanner for direct illuminance direct irradiance, diffuse illuminance, diffuse irradiance

The vertical axix of the Sun Tracler turns a table which follows-controlled by the supplied Sun Tracker control unit-the suns' azimuth position. The table carries the two sensors for diffuse sky illuminance／irradiance and the motor for a horizontal axis. To the horizontal axis the heads for the direct sun illuminance／irradiance quantities can be mounted in a way, that they are turned around their light sensitive area. The horizontal axis turns also a special holder for screens which prevent the sensors to be irradiated by direct sun light.

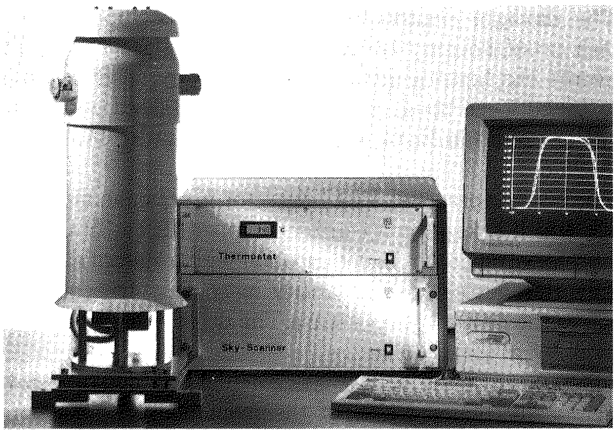

Figure 5 Sky Scanner with Control and Data Acquisition System.

5. Sky luminance distribution measurement

A Sky Scanner was devlopped for the measurement of the sky luminance distribution.

The Sky Scanner is a photometer for the fast measurement (≒ 20 s) of the sky luminance distribution made for a longlasting largely maintenancefree outdoor use. By the Sky Scanner the sky luminance distribution is measured in 145 nearly equidistant directions, and, in addition, a five times done measurement of the zenith luminance. The sun position is left blank , in order avoid damaging the $V(\lambda)$ -Si-photovoltaic cell. The luminance is measured with a 10° view angle.

The Sky Scanner consists of three units (Figure 6) :

- photometer head with turnable optical system and the Si-photovoltaic cell
- Sky Scanner control unit
- Thermostat

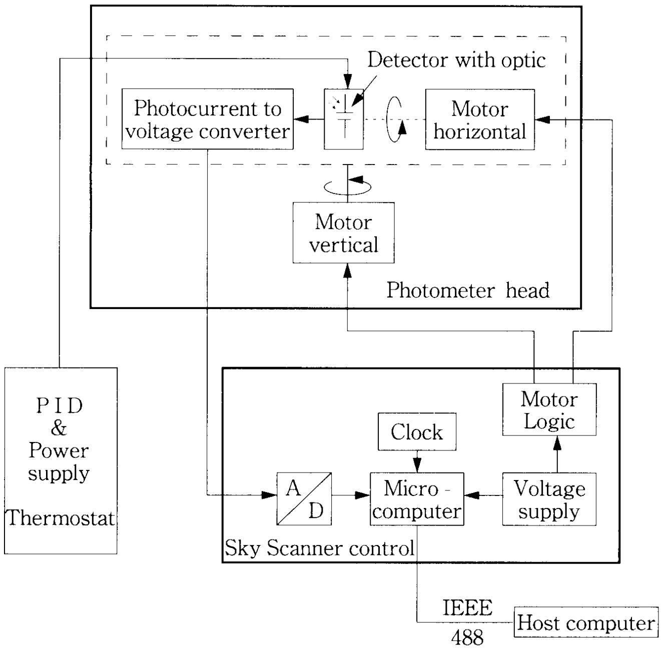

Figure 6 Simplified schema of the Sky Scanner system

While the photometer head is designed for outdoor installation, the control and data acquisition unit and the thermostat has to be placed in a sheltered way inside a 19" rack.

Figure 7 shows a schematic drawing of the sky scanner's photometer head. The aluminium housing is protected by a fiber glass cover in order to prevent heating up by direct sun irradiance. The base (9) can be mounted on a flat surface. For horizontal alignment an adjustment facility (8) is provided. Though the Scanner's control system is able to oreintate itself into the correct geographical direction it must be positioned roughly. For that, it is possible to turn the Photometer Head around its vertical axis (7). All electrical connections are made by two waterproof heavy duty connectors (6). These connectors must be plugged and locked in when keeping the Photometer Head outdoors, even if the instrument is not used.

The main body (5) contains the stepper motor of the vertical axis together with the mechanism for a reliable cable carrying. This part is separately thermostated to provide proper function also in the cold seasons.

The movable part (4) is basically the heart of the Sky Scanner. It turns around the vertical axis and contains the optical part (see Figure. 8). Special precautions are made for keeping this part (1) absolutely dry inside. The entrance optic (2) turns around a horizontal axis and is automatically cleaned by every rotation. Under the top cover (3) a fan is installed. This provides an air flow from the base of the Photometer Head to the top and removes waste energy from the thermostatisation and direct sun irradiance.

The optical system was especially designed for this task. In order to insure a constant directional response within an 10° view angle and minimize the influence of polarized light.

A schematic drawing (Figure 8) explains the basic way of operation.

The acceptance area (A) is formed by an achromat which reflects the sighted sky sector-by means of a prism (O)

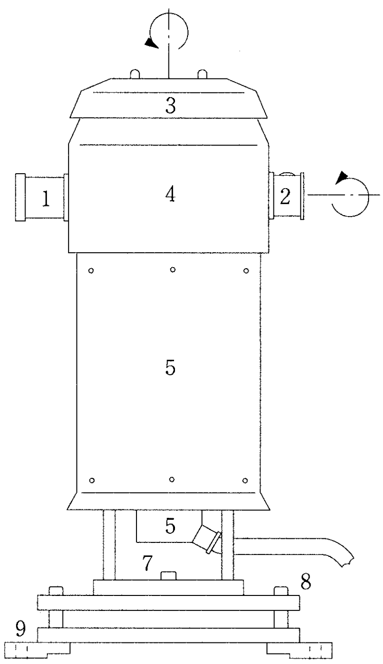

Figure 7 Schema of Sky Scanners Photometer Head

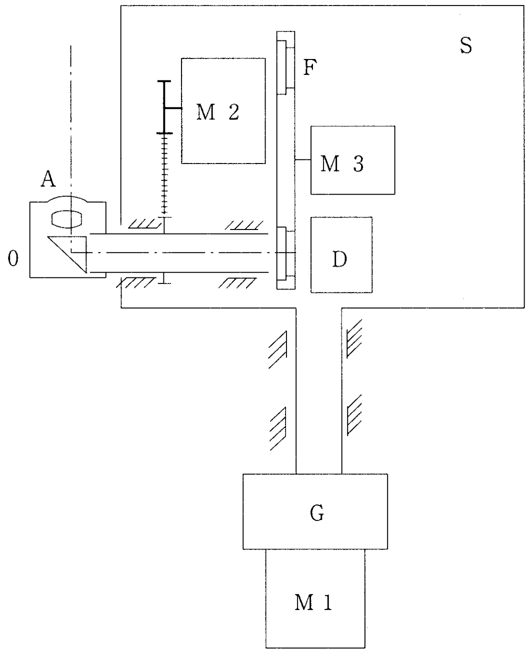

Figure 8 Schematic of the Sky Scanners optical setup

on to the photovoltaic cell. Additionally, a motor diven (M 3) filter turret (F) is mounted into the beam path. This is used to block the beam, set the $V(\lambda)$-filter a neutral filter and up to two additional edge filters in front of turret, which is fail-save prevents incoming light to reach the detector. Direct sun irradiance cannot damage the detector by this.

A neutral filter is provided in the turret to support the system's self adjusting facility when the entrance optic faces the sun.

By the turret not only photometric data can be measured but slso separated radiation in the blue or red spectrum range, which allows the detection of clouds.

6. Color measurement

A tristimulous colorimeter[5] with direct display of x and y as well as correlated color temperature is used for measurements of color similar to horizontal global illuminance. The display unit is connected with the outside positioned colorimeter head. The acceptance area is 11mm in diameter and cos-corrected.

7. Data acquisition system

All photometer heads are positioned outside and are splash waterproof, while the data acquisition system must be positioned inside. Each logical unit of photometer or radiometer uses an owan data acquisition device. This has advantages building up a modular daylight measuring station and follows the demand for parallel measurement of all connected units.

Further on, the controlling software can be clearly arranged. The Illuminance Data Acquisition System uses basically a precise DMV with a scanner input. This arrange-

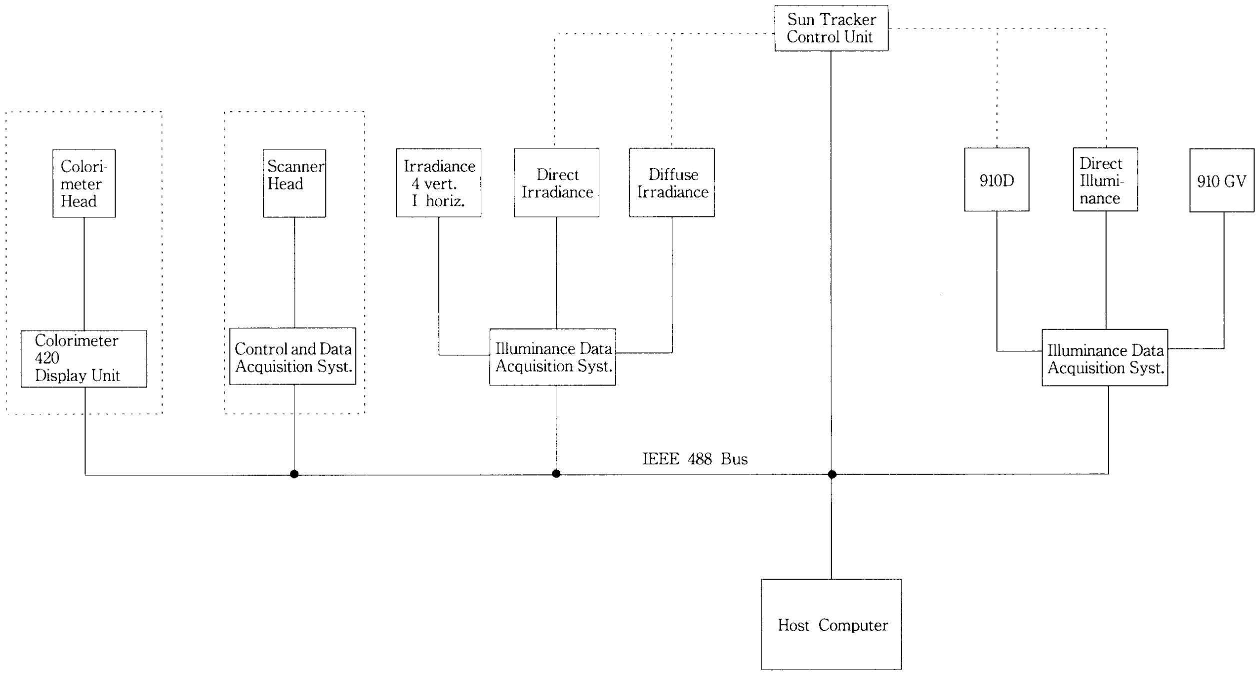

Figure 9 Block diagram of a complete daylight measuring system

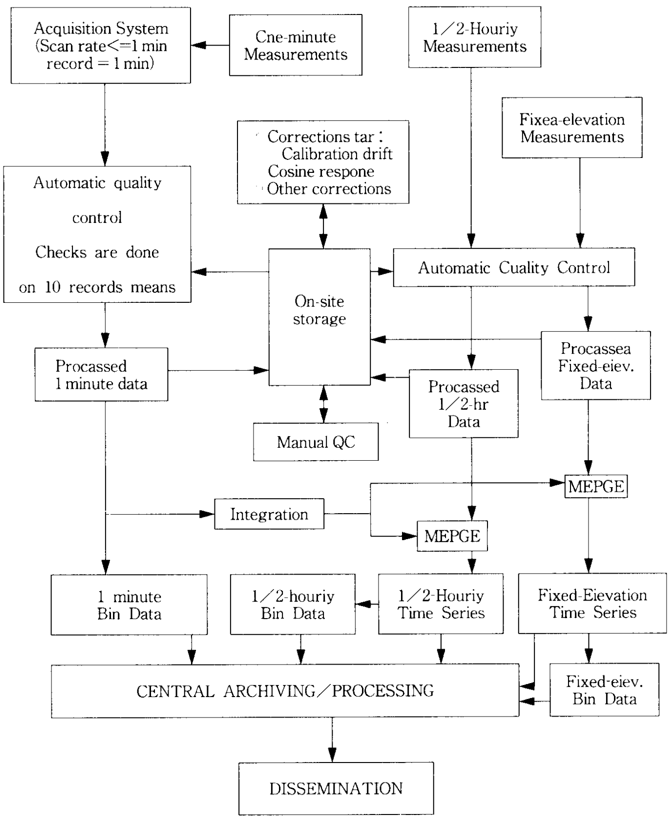

Figure 10 Data Acquisition / Processing flow chart

ment is a good compromise between neasuring time and instrument cost.

In order to control all the measurements, a special software running on a PC has also been develobed. It includes the necesary quality control for the measured data and generates standardized files as recommended[15]. By this, all the measuring stations can easily exchange their data. The recommended flow chart is shown in Figure 10.

8. Irradiance measurements[4]

Special radiometer heads with pyranometers as radiation detectors are used for the measurements of irradiance data.

They are arranged simular to the photometer heads as described before. As these detectors use a thermal effect with reference temperature, no thermostatisation is necessary. Instruments like this are already approved by metrological measuring stations and must not be described here.

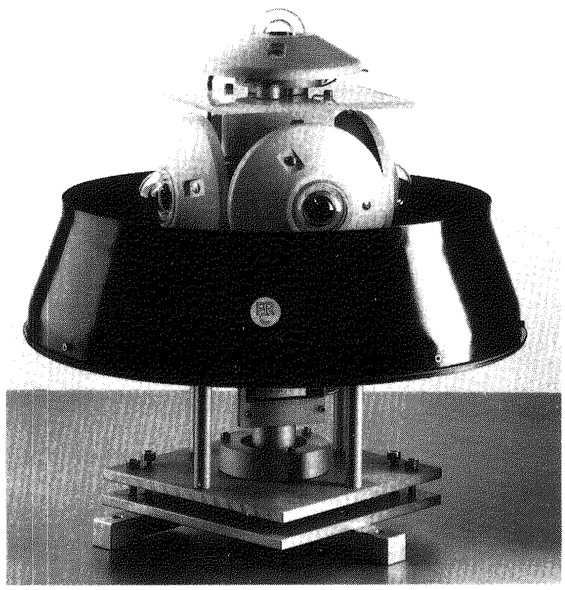

Figure 11 Radiometer Head for global horizontal and N-S-E-W vertical

9. Reflectance

The daylight measuring results may be influenced by radiation reflected from ground obstruction. Therefore, the reflectance ρ_{dif} at diffuse incidence of light should be measured directly with a ρ_{dif}-meter[6]
This instrument should be battery powered, but not necessary for permanent outside use.

10. Cloudiness

The knowledge of cloudiness of the atmosphere is necessary for a complete survey on the sky cfonditions. This is measured normally by a visual sky observation. A two filter method is proposed by Emmrich[7] instead of the visual inspection. Two filters can therefore be built into the Sky Scanner. Agreements for the filters and the evaluation of measuring results are necessary for the future.

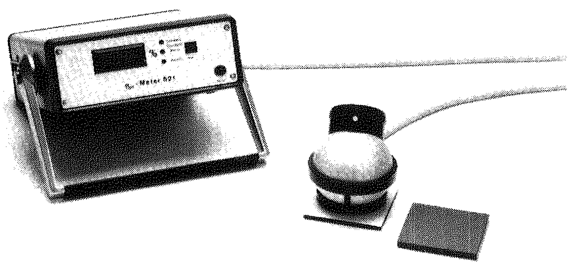

Figure 12 ρ_{dif} - Meter

11. Sunshine Duration

The measurements opf sunshine duration can be measured according to the recommendations of the WMO[4]. It describes an International Reference Sunshine Recorder, which records a burnt trace on a standardized card. Another possibility is to take the time, where the direct sun irradiance is at least 120W／m².

12. Recalibration

Photometric equinpmeng should be recalibrated in yearly intervals as it is recommended for all measuring devices, especially if they are used in rough outside conditions.
It is proposed to send (e.g. from PRC Krochmann, Geneststr. 6, D-1000 Berlin 62), thoroughly calibrated precise photometers for loan to the relevant stations, for comparison measurements with those pohtometers, which are permanently used for the measurements. By that, the necessary corrections can be done. The reference photometers are then sent back and are recalibrated again, to find changements of the calibration equipment. The results are reported afterwards to the measuring stations. This procedure has the great advantage, that the time loss in a continuous working station is minimized.

The calibration equipment must be thermostated, but not waterproof. Equipment is available for
- horizontal and vertical global illuminance
- sky illuminance
- direct sun illuminance
- zenith luminance

The equivalent radiometers are also available for recalibration.

13. Characterization of glazings

The prediction of inside daylight and solar radiation is only possible, if the data of used glazings are known. The characterization of glazings, which must be known for this are at least[10, 11] :
- luminous reflectance an transmittance for stadard illuminant D65
- radiant reflectance and transmittance for global radiation
- total solar nenrgy transmittance (solar factor) to be calculated

These data must be known as a function of the angle of incidence.

A measuring equipment (integrating sphere) is develobed, for integral measurements of these quantities using simulated D65 and global radiance.

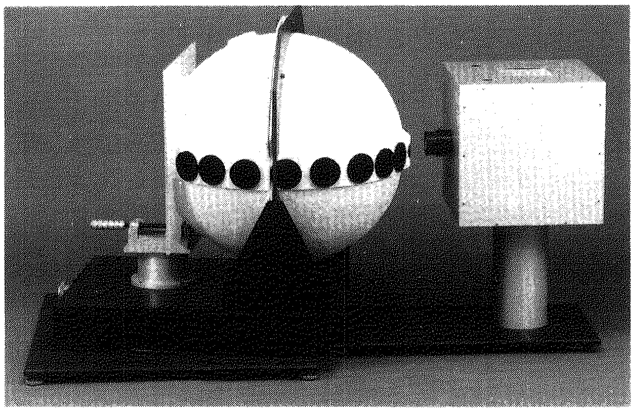

Figure 13 Universal ρ/τ - Meter for photometric and radiometric measurement of characteristics of materials

The shpere has a reflectance of $\rho \approx$ 0.8, constant in the wavelength range between 300 nm and 2.5μm. As detector a photometer head with very good $V(\lambda)$-correction for luminous quantities and a pyro-electric detector for radiant quantities is used.

14. Daylight prediction in Germany

With support by the European Community a prediction method for the availability of solar radiation on inclined surfaces was developed by Aydinli[12]. The method is based on overcast and clear sky conditions, which are non-linear averaged according to the sunshine duration.

The same method is used for daylight predictions using the luminous efficiency of overcast and clear sky and direct sun data. For the daylight inside a building the sky luminance distribution of overcast and clear sky is used with the mentioned superposition. By this, local average daylight predictions are possible.

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Literature and data sheets of instruments are available from the author.