XXXII IAHS – Daylight-transfer systems: physiological and energetic advantages

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Key words: comfort, sustainability, light transfer, new materials.

Abstract
Daylight-transfer systems are devices designed to operate according to the law of reflection: they collect and transfer it to rooms lacking in light. On the whole, possible applications can deal with rooms which do not communicate directly with the outside. For instance, it can be the case of both basements and large-sized buildings like those devoted to the service industry.
In recent years, the considerable attention devoted to sustainable development has prompted planners to reconsider the use of daylighting in architecture.
Current research, partly examined in this article, aims at producing a range of systematised products and techniques according to some specific characteristics in order to highlight the advantages of these systems in terms of energy conservation as for essential artificial lighting and, consequently, to contribute towards decreasing the use of non-renewable sources of energy and related problems about sustainability.

1 Properties of light transmission systems

Daylight-transfer systems are composed of two main functional units: a **light collecting** unit and a **light transmission** unit**.** The first unit is made up of specular surfaces strategically oriented so as to collect sunbeams and convey them to the transfer unit; the second unit consists of plane mirrors, parabolic mirrors, and Fresnel lenses, used separately or combined together.
Light collectors can be either mobile or fixed. The first type, designed to be constantly sun-oriented, collect light and concentrate sunbeams by means of active systems.
The daylight collected is conveyed through the **transmission** unit which is composed of pipes whose high reflecting materials allow long-distance irradiation.
Daylight transmission systems can be either mobile or fixed tracking systems depending on the transmission system employed.

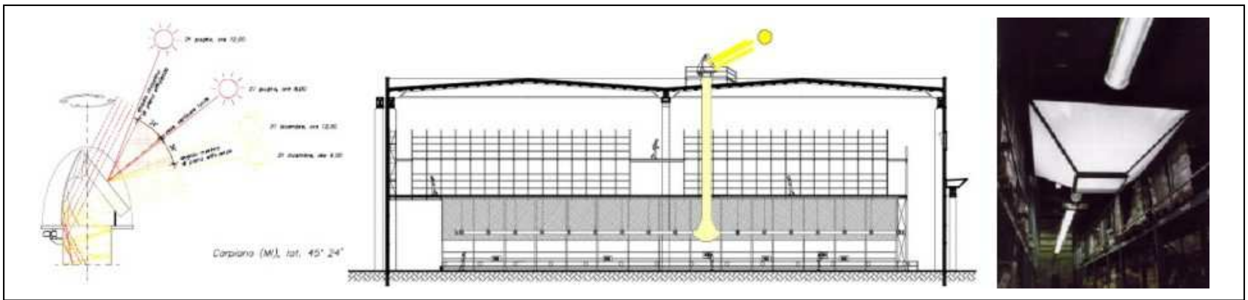
Mobile tracking systems (fibre optics and liquid optic guides) are produced regardless of the application they are designed for. They can be easily integrated in any building thanks to their considerable flexibility: they can bend in a limited space, reaching any part of the building. In such systems, daylight transmission is based on the law of reflection and provides lighting without heat and harmful radiations. It can be either end lighting or lateral-emission lighting.
Fibre optics are flexible cables with limited cross-sections, made up of transparent dielectric material, e.g. glass and PMMA (polymethyl methacrylate), while the liquid optic guides consist of a pressurised flexible pipe comprising a Teflon cladding filled with a liquid and plugged on both ends. The liquid can be either an alcohol base or a saline base. .
Fixed tracking systems (light pipes and mirrors) are specially designed for each case. Once they have been installed their position can not be modified: they have therefore a restricted range of applications.
The following table shows an overview of the properties of the existing systems dealt with in the following chapters.

		COLLECTING						TRASMISSION				SCATTERING		ARTIFICIAL LIGHT ADDING	EFFICIENCY
		MIRROR		FRESNEL LENS	NOTHING	MOBILITY		OPTICAL FIBERS	LIGHT PIPES	LIQUID OPTIC GUIDES	NOTHING	DURING THE PATH	BITTER END		
		PLANE	CURVO			MOBILE	FIXED								
FIXED TRACKYNG SYSTEMS	ARTHELIO CARPIANO			■		■			■			■	■	■	1
	ARTHELIO SEMPERLUX ARTHELIO BUT	■		■		■			■			■	■	■	1
	BOMIN SOLAR GERMANIA	■					■				■	■			
	BOMIN SOLAR SVIZZERA - GERMANIA	■				■					■	■			
	BOMIN SOLAR WASHINGTON	■				■			■			■	■		
	CADETT PROJECT		■				■		■				■		
	HELIOBUS GERMANIA	■				■			■			■	■	■	
	HELIOBUS SVIZZERA		■			■			■			■	■	■	
	SOLARSPOT OIKOS	■					■		■				■		1
	SOLARIS	■				■					■	■			
MOBILE TRACKYNG SYSTEMS	UFO			■		■				■			■	■	0,7
	HIBRID-LIGTHING		■			■		■				■	■	■	0,5
	HIMAWARY			■		■		■					■		

Most of these systems are currently in production, whilst the ARTHELIO system is a European research project based on the combination, the transmission and the scattering of daylight combined with artificial light.

1.1 ARTHELIO – Installation at the European Centre 3M in Carpiano (Milan)

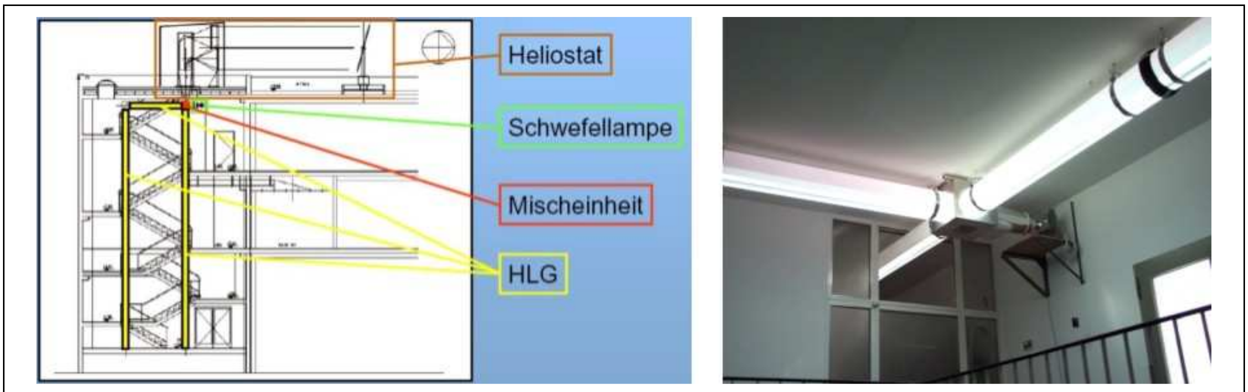
The collector is composed of a Fresnel lens which focuses throughout the year almost every solar elevation angle through a simplified rotation around the vertical axis of the collector itself. It also allows a diffuse component of daylight to enter. The pipe is roughly 13m long and 90m across, it is opaque on the outside, while inside it is lined with a highly reflecting dielectric material (3M Visible mirror film). This material is made up of a multilayer polymeric film with a reflection coefficient of about 99%. At the basis of the pipe, daylight is transmitted outside by the diffuser.
A combination with artificial light is possible, made in such a way as not to mix them in order not to lose the physiological and psychological benefits of daylight. Particularly, a system of sensors detects the level of natural illuminance. When a sensor detects the minimum threshold of illuminance, it increases the luminous flux of the lamp and at the same time integrates daylight through a system of pipes and motorised baffles placed near the diffuser.



Installation at the European Centre 3M in Carpiano (Milan)

1.2 ARTHELIO – Installation at the Semperlux (Berlin)

The collector is composed of a heliostat with a surface of $6m^2$ which concentrates sunlight onto 4 Fresnel lenses having a focal length of 12m. Directly behind the focal spot are 4 parabolic mirrors which diverge the light downwards into the light pipe.
Light is transmitted through a transparent plastic pipe with a diameter of 30cm lined with an optical lighting film (produced by 3M).
The transparent film has a smooth surface on one side and longitudinal microprisms on the other. The light hits the film with a low angle of incidence which allows an overall internal reflection. Moreover, some reflecting cylindrical extractors facilitate light scattering in the inner rooms.

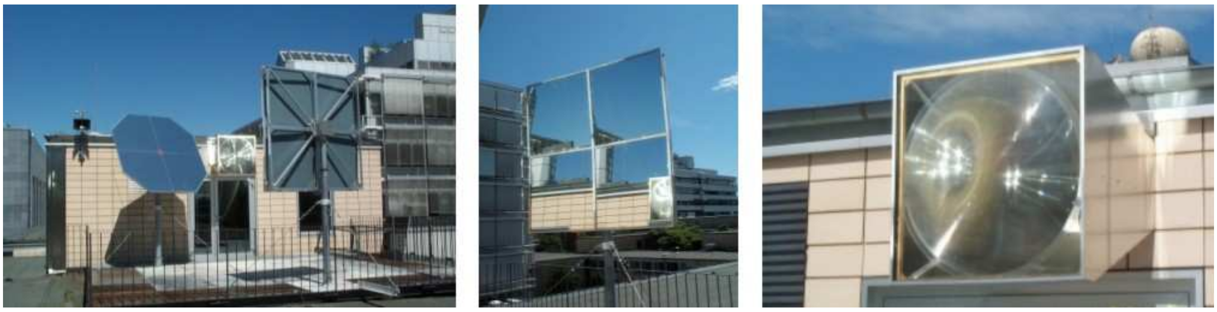


Installation at the Semperlux (Berlin)

These extractors hang from the centre of the light pipe in a particular order according to their diameter which increases proportionally from the top to the bottom of the pipe. The system consists of two vertical parallel pipes lighting a three-storey stairwell. One of them is placed under the collecting unit with which it is directly connected. The other pipe is supplied with light by the first through another light pipe installed horizontally on the roof. This connecting pipe is provided with a sulphur lamp at one end, whilst a unit placed on top of each vertical pipe combines sunlight and artificial light in order to distribute them uniformly to the vertical pipes. A similar method using reflecting cylindrical extractors is employed in the Heliobus system.

1.3 ARTHELIO – Installation at the University of technology (Berlin) BUT

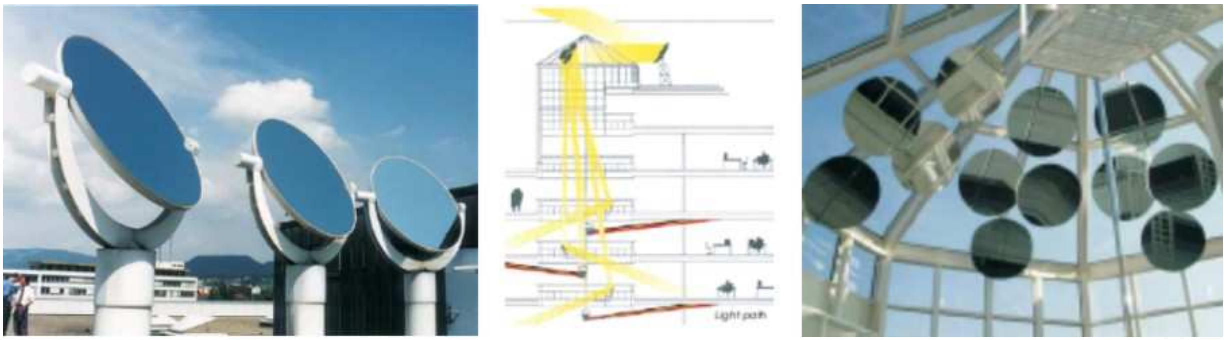
The heliostat is composed of a two-axis rectangular mirror to reflect sunlight onto Fresnel lenses with an optical diameter of 0.9 metres. It also uses a secondary mirror having several segments which can be moved independently to give the optimal concentration. The light is directly transmitted by the Fresnel lenses to the light pipe lying behind.
The light pipe is placed horizontally, has a large cross-section and scatters light over a small room. The difference with the Semperlux system is that the latter one has no secondary mirror.



Installation at the University of technology (Berlin) BUT

1.4 BOMIN SOLAR

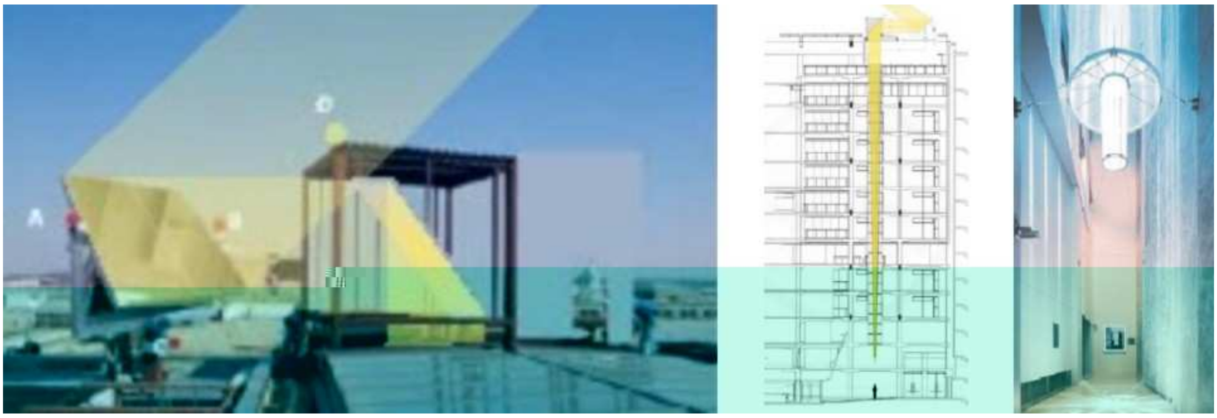
The system is composed of several collectors (primary mirrors) which are fixed as in the installation of Karlscharnagel. On the contrary, at the Administration Building of Zurich and at the Underground Station Altenessen of Mitte, they follow the course of the sun by rotating around two orthogonal axes.
It also consists of a system of secondary mirrors transmitting daylight inside the building.



Collectors installed at the Administration Building in Zurich

1.5 BOMIN SOLAR - (Solar Light Pipe, Washington, USA)

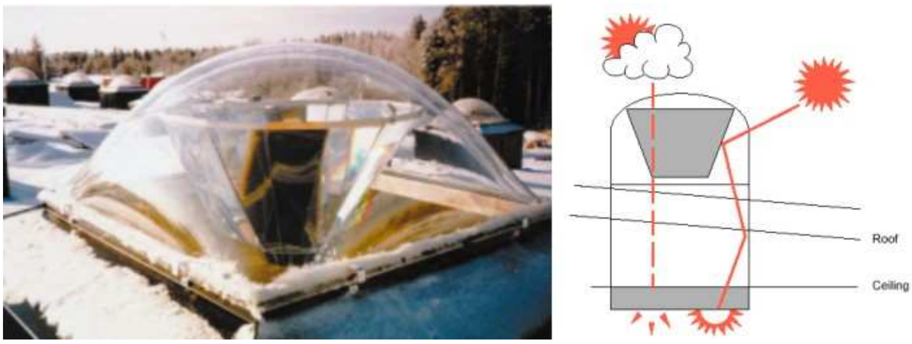
The system consists of a plane specular collector, which is mobile on either axes of rotation and placed at the top of the building. It reflects sunlight onto a secondary mirror which in turn conveys it to a light pipe narrowing downwards. Such a light pipe both reflects and scatters sunbeams along its whole length of 30m.



Functioning system of the Solar Light pipe in Washington.

1.6 CADETT

The system collects both diffuse and direct sunlight through a double dome of transparent polycarbonate containing a specular prismatic cone made up of the same material. Like a mirror, the cone conveys sunbeams into the highly reflecting light pipe.



Collector of the CADETT system.

1.7 HELIOBUS (Postdam Station of Berlin Underground)

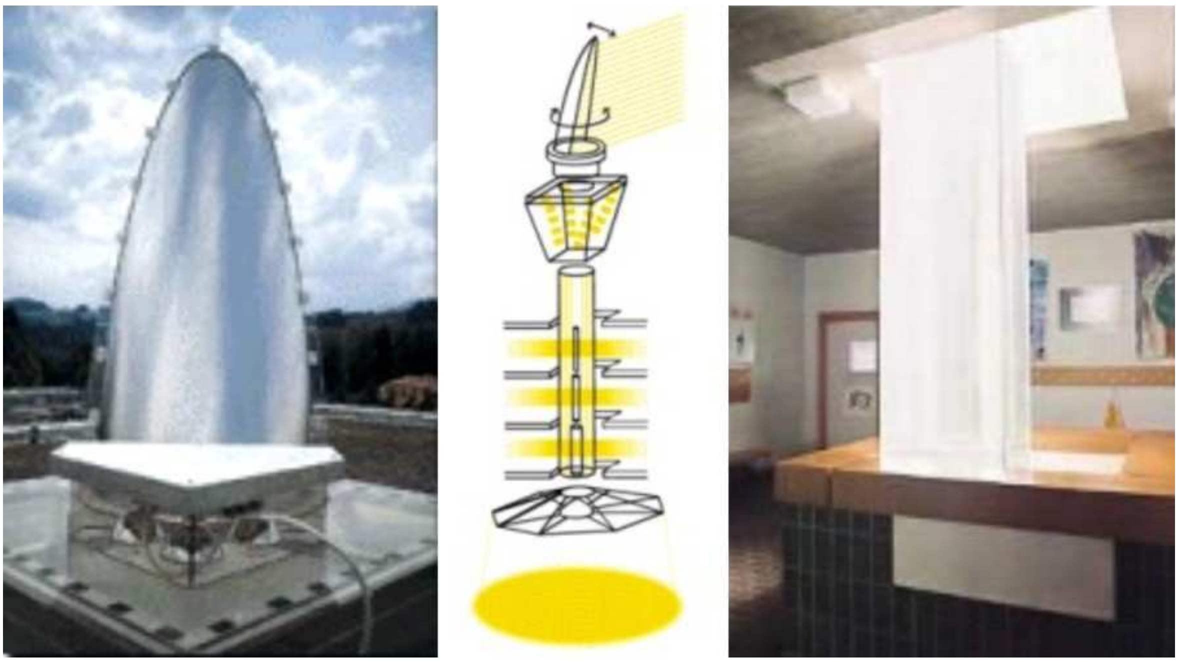
The system consists of an oval plane collector, installed at the top of each pipe, which follows the course of the sun and diverts sunlight inside. The light pipe consists of a glass pipe enclosing a steel pipe placed at a certain distance. This one is covered with a highly reflecting foil which diverts daylight underground. At the bottom of the pipe a part of the glass material allows light scattering.

Artificial light can be added where the pipe cuts the floor. At night, the pipes are lit by artificial light so that they are extremely visible at Postdamer Platz.

Comparison between day and night at Postdamer Platz

1.8 HELIOBUS (Boppartshof school in St. Gall Switzerland)

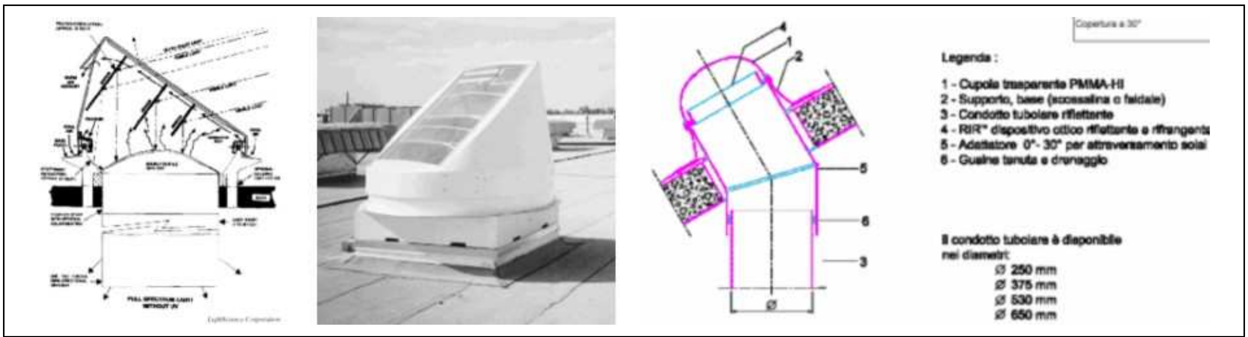
The system is composed of a concave collector with an aluminium bearing and coated with a highly reflecting specular surface protected by a transparent plastic screen.
The collector is 2.25m high and its base has a diameter of 1m. It can follow the course of the sun by means of two axes of rotation. The light pipe is about 10m long and has a square section with a side of 62,5cm. It is composed of a transparent material (10mm thick). It is lined with a prism-patterned film (produced by 3M) allowing the reflection as well as the scattering of light over the floors. The light pipe contains some reflecting cylindrical extractors which help light scatter over the floors. Their diameter varies in proportion to the distance of the collector. Should there not be sufficient illuminance, a combination with artificial light is also possible.



Functioning scheme of the Heliobus system installed in Switzerland.

1.9 SOLARSPOT/OIKOS

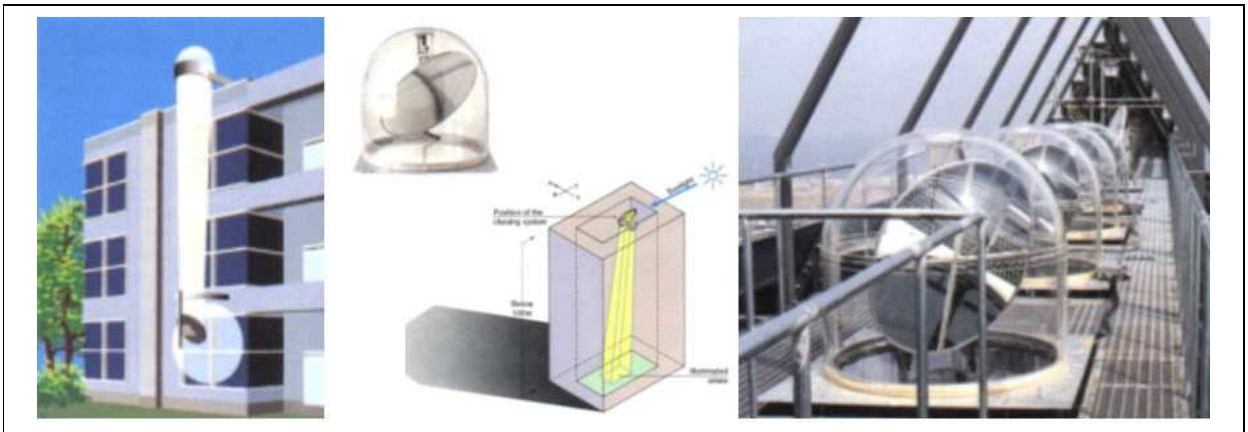
These similar systems have two different types of collectors. The Solarspot collector collects the beams of light from every direction through a polycarbonate dome containing two different corrective devices (bireflecting and coaxial optical prisms) which guide both the direct and the diffuse radiation according to a functioning model known as Reflected Interactive Refraction. The Oikos collector is composed of thin specular plates placed perpendicularly to the surface collecting sunlight.
Both use a light pipe for the transmission. This pipe is made up of multilayer reflectors (UMF) designed not to reflect the infrared ray and which act as cold mirrors transmitting light and not heat and reducing summer overheating.



Collectors of Solarspot/Oikos systems

1.10 SOLARIS

The system consists of plane mirrors directing sunbeams to other mirrors which are placed so as to light some specific parts of the building. Such a system allows following the course of the sun thanks to a photosensitive cell. Light is transmitted solely according to the law of mirror reflection.

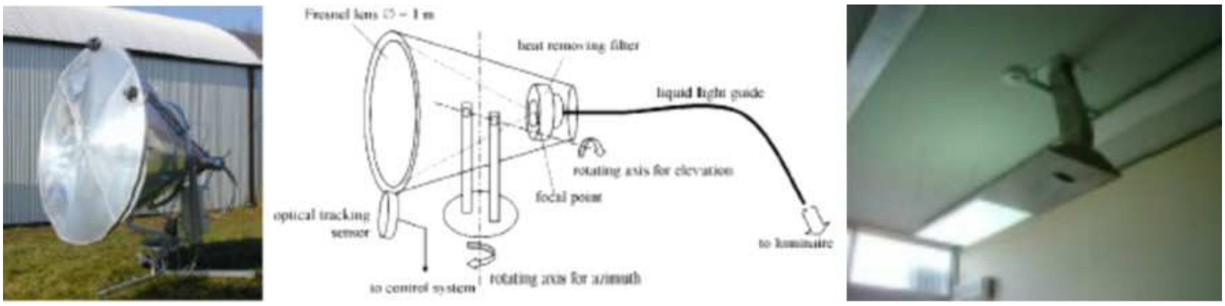


Functioning schemes of mobile collectors in the Solaris system

1.11 UFO (Universal Fibre Optics)

The collector of this system has a diameter of 1m and is composed of transparent synthetic material. The collector rotates around both the orthogonal axes to follow the sun. It is moreover oriented so as to

be constantly perpendicular to sunbeams. Light transmission is based on the whole reflection inside a flexible pressurised pipe (2cm of diameter) lined with a Teflon cladding. This pipe contains a liquid which is either an alcohol base or a saline base.
Light is directed onto the fibre optic guide, after being filtered and deprived of heat to protect components from overheating.
Should there be no longer daylight, artificial light source assures the required levels of illuminance. Such a source is controlled by a photocell system which rations the amount of artificial light in accordance with the detected levels of illuminance. Sunlight and artificial light are combined directly within the diffuser to avoid any dispersion of artificial light.



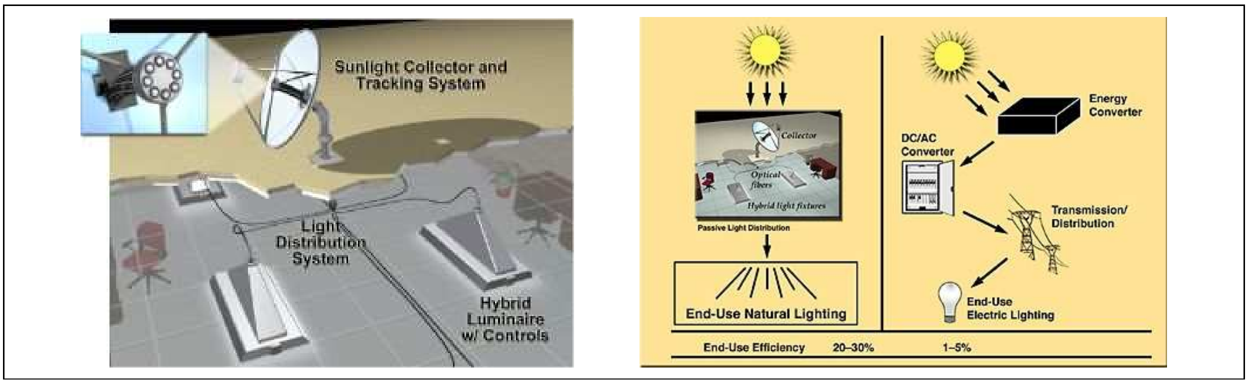
Collector and diffuser of UFO system

1.12 HYBRID LIGHTING

The system consists of a parabolic primary mirror reflecting non-diffuse sunbeams onto a secondary optical element (SOE) placed in the focus of the parabola. The collector rotates around two axes of rotation. Light is transmitted by means of 8 large-core fibre optics placed at the centre of the parabolic mirror.

Collector and diffuser of Hybrid Lighting System.

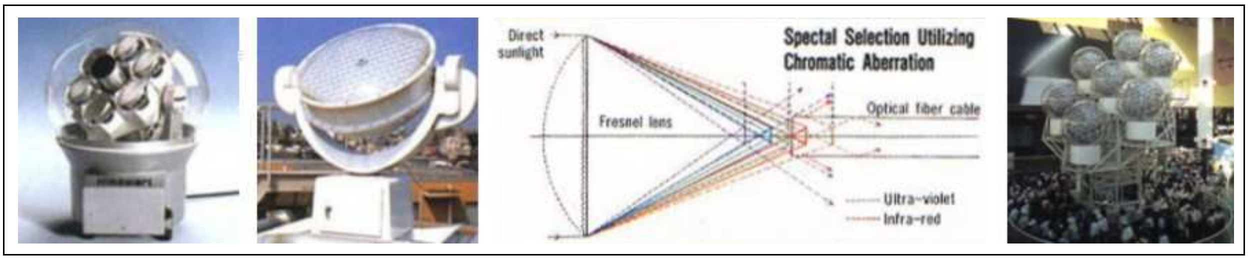
The system is called hybrid lighting since it combines daylight and artificial light when required by weather conditions: a control system allows the combination of daylight and artificial light to achieve constant and suitable levels of illuminance.
Being spectrally selective, the system separates the visible portion of the solar spectrum from the infrared spectrum by means of a cold mirror (SOE) transmitting the infrared rays to a photovoltaic cell to generate electricity.



Functioning schemes of Hybrid Lighting System

HIMAWARI

The system consists of a sunlight collector whose honeycomb-patterned surface is composed of a series of Fresnel lenses placed side by side whose number varies according to their size.
The collector moves thanks to a photosensitive cell (installed at the centre of the collector) which sends impulses to the engine by means of a microprocessor. Light is transmitted through a fibre-optic cable containing 6 fibres per each Fresnel lens. The fibre optic end is positioned in the focus of the visible spectrum obtained by sunbeams crossing the lens: thanks to this position both ultraviolet and infrared rays are excluded.



Collectors of Himawari system

2. Conclusions

Daylighting plays a key role in architectural design not only as for the control of energy consumption during the day but also for its beneficial effects on human health. A higher quality of daylight in working environments, namely a better chromatic yield, results in an increased working efficiency, whilst artificial light can stir the attention in the short run but causes fatigue in the long run and, consequently, a reduced working efficiency. The use of these systems could determine a reduction in energy demand particularly in the peak hours (late morning and early afternoon). Energy conservation is due to the lowest energy consumption for both lighting and summer air conditioning, the latter one being a result of reduced thermal flows spread by the lamps. In temperate climates, for every 1000 kWh consumed for lighting there is an estimated further consumption of 30 kWh for air conditioning. Moreover, energy savings help reduce the use of non-renewable sources of energy and all the related problems.
However, the level of artificial illuminance needs to be modulated according to the natural level available in order to obtain an efficient energy conservation.

Reference

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