Daylighting with POF[1]

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Abstract: Using daylight for direct illumination has been a subject of high priority for R&D activities over the last years. Several international projects have been finished, none of them leading to a commercially available product. Possible arguments for a commercial success have been investigated. A first demonstrating system implementing these ideas has been built up and tested.

Introduction

Using daylight for direct illumination has been a subject of high priority for R&D activities over the last years. Most of them are related to directing the sunlight by specially shaped venetian blinds towards the ceiling of the room for further distribution. Some of them dealt with transporting the light, either collecting directed light from the sun or diffuse light from the sky through light pipes. These light pipes have been hollow or rigid, using dielectric or metallic reflection.

Background & motivation

An estimated 35% of electricity used in the United States is expended on lighting interior spaces in daytime. Ironically, the working day coincides with the hours that the sun is strongly illuminating the whole hemisphere. The goal is to reduce the need for electricity with fiber-optic lighting thus using the sunlight directly. Direct use of daylight is desirable because of several reasons:

- Energy conservation
- Positive influence on human performance and well-being.

In the past a variety of approaches have been proposed, starting with the Himawari system [Him 86] more than 20 years ago to recent systems like Parans [Par 07], but to our knowledge, the final market entry has not yet occurred. We think, the systems should be simpler using smaller modules that can be combined to larger units according to the area available. In addition for keeping the colour distribution of the daylight the length of POF has to be kept shorter than typically 10 m, so we favour a combination of POF, where the light guide has to be flexible and rigid light guides (e.g. tubes with highly reflecting inner walls).

Expected advantages of fiberoptic daylighting

The main technical advantages may be expected in the following areas:

1. Direct daylight use has higher efficiency, thus leading to **massive cut of energy costs** as can be seen considering two obvious facts:
   - The amount of light shining during a sunny day on **1 sqm** is sufficient for **500 sqm** needed in parking lots or stair cases
   - Usually the process chain for lighting is at follows: The sun produces fossile (or as recently exploited: renewable) energy carriers such as gas, oil, coal etc. This chemical bonded energy is transformed in power plants into electrical energy with losses typically 50%. The electrical power has to be transported to the end user including losses due to transformation and along the cable. There in most cases incandescent lamps are used, transferring only typically 10% of the arriving energy into visible light (in some cases additional energy is needed for cooling) ending in an efficiency in the order of a few percent only! This means that a **direct use of sunlight could be much more effective.**
2. In the meantime fiberoptic lighting using EFO® [EFO 07] technique (efficient fiber optic) offers a much **higher end efficiency** compared to "classical" light bulbs using a reflector.
3. Using light guides for transport and distribution of light offer new opportunities and new design approaches for designers and architects.
4. Cost reduction also for maintenance because light sources do not need maintenance (sun) or because artificial light sources can be installed in easier accessible locations.

Since there will be no/less electrical components outside the building this will lead to **reduced efforts for safety measures** and opens illumination for areas, where it has no been feasible because of safety issues (explosive environment, humidity, etc.) or needed expensive insulation efforts.

State of the art

In Europe there have been some activities, both on the more or less scientific side such as some projects funded by the European Commission (EC) within the framework of the Joule-Program:

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- **Arthelio** (until 2000) using large diameter (about 10") hollow light pipes with 3M OLF (Optical Lighting Film) and a combination of sunlight collected through a heliostat mirror-lens assembly and of artificial light to stabilise the level of illuminance [ART 01]
- **Spectrum** (until 2002) using small core silica fibers and sun tracking parabolic reflector assemblies arranged in arrays [Spec 03]
- **UFO** (until 2002) using liquid core fibers and sun tracking Fresnel lens [ufo 02]

as well as on the commercial side like

- Egis: www.egis.org/Helio_de.html
- Solatube: http://solaglobal.com/
- Heliobus: www.heliobus.com/pages_e/frames.html
- Solux: www.bomin-solar.de/
- Parans: www.parans.com

In the USA there have been activities at the Oak Ridge National Laboratories which lead to "Sunlight Direct". In 2004 this a spin-off company started the commercialisation of the hybrid solar lighting (HSL) project, using sun-tracking parabolic mirror dishes (typ. 1 m diam) and fiber bundles, guiding the light to the interior of the building (www.sunlight-direct.com).

Maybe the most widespread commercial use has been in Japan with the Himawari system [Him 86].

Preliminary investigations

In a first stage [Gab 06] we analyzed the state of the art and compared the different geometries to track the sun using a lens-to-fiber coupling with a multiplicity of those units. For collecting directed sunlight only 2-axis tracking is useful, but there is a variety of conceivable arrangements as shown in Fig.1.

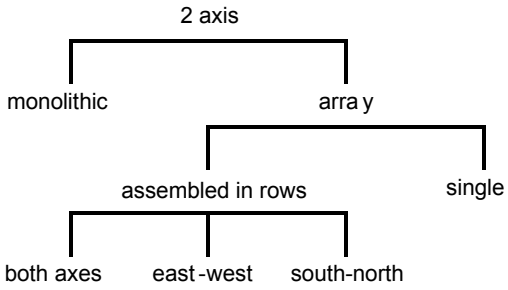

Fig.1: Geometries investigated by simulation

Using a raytracing program (LightTools®) we calculated the respective efficiencies, also distinguishing between single or double panel constructions, one for the morning, the other for the afternoon period. As an example of the results achieved, Fig. 2 shows the luminous flux for a double array with lenses coupled in panels oriented north-south direction which can rotate east-west. In order to cope with the respective shadowing of the rows a distance of ¼ of the optics diameter has been introduced additionally.

According to these investigations we drew the following conclusion for a system which might be accepted by the market:

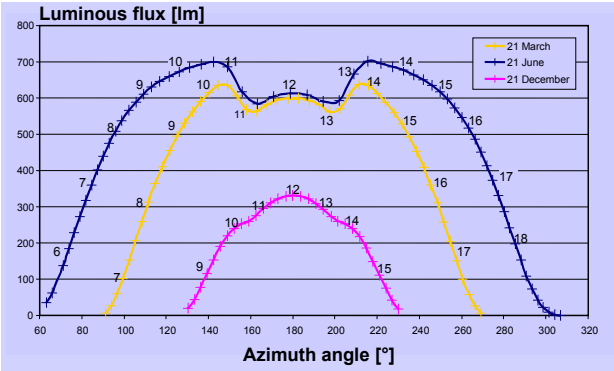

Fig.2: Luminous flux collected at 3 different days in a year at the position of Nuernberg university. Numbers at traces indicate the time of day

- Modular construction to become less expensive
- Flat to be mounted on tilted roofs
- Simple mechanics and injection moulded optics
- Hybrid approach for light transport, i.e. fibers + rigid tubes
- Implementing new approaches from concentrating photovoltaics (CPV)

After we had finished this survey which had been published in [Gab 07] , the Swedish company Parans came up with an approach addressing a great part of our requirements, but not all [Par 07].

Experimental set-up

In a first step in order to learn we constructed a 4x4 array which had to be manually oriented to the sun (Fig. 3)

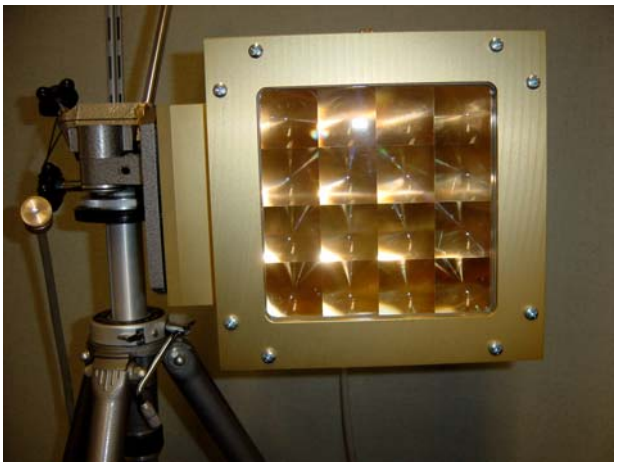

Fig.3: First array with 40 mm Fresnel lenses

This is more or less the construction we assume Parans is using. In the next step, we improved the optics. Based on the proprietary CPV approach used by Sunvention [Sun 07] we designed light collecting which can be easily coupled to a polymer optical fiber (POF). The fibers of all units are coupled to a bundle which is still flexible enough to follow the movement of the elements

while tracking the sun. The length of POF is restricted to the section where a flexible light guide is needed since it is well known that POF absorb in the orange-red regime of the spectrum, yielding green light already after 20 m of transport through the POF.
For longer, more or less straight lengths, the use of hollow light guides is planned, thus conserving the natural spectral distribution of the sunlight transported to the interior of a building.
Fig. 4 shows an engineering drawing of the experimental set-up. Not only are the elements within one unit made out of modules, each of them concentrating the sunlight by a factor of 200, but also can these units be arranged to a mosaic which can be matched to the space available.

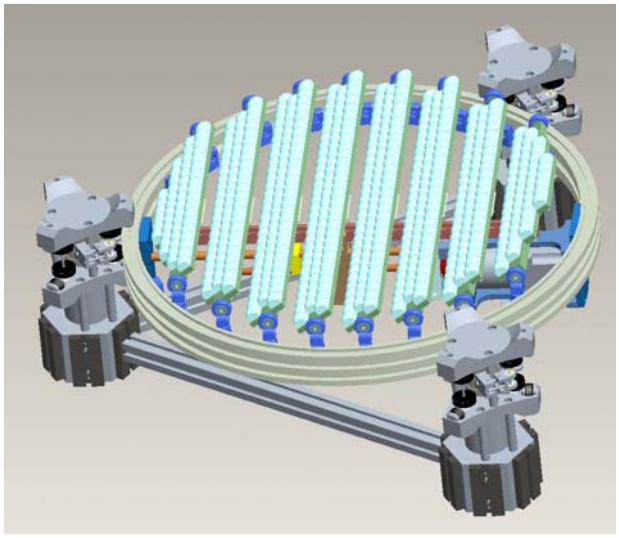

Fig.4: Engineering drawing of one module with about 600 ”eyes” orientet to the sun; 3 pistons for bearing and drive

The modules as shown in Fig. 4 can be arranged like a mosaic in very flexible geometries (Fig. 5).

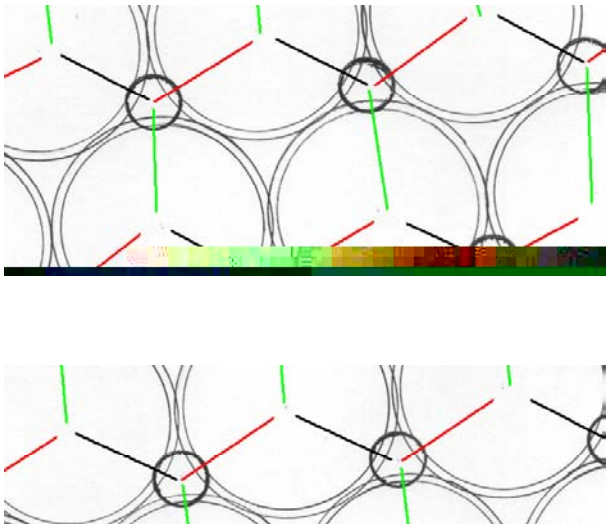

Fig.5: Mosaic of several collecting modules

Results

At the moment of writing this paper, the set-up with an effective diameter of 50 cm using about 600 individual collecting units, is in the stage of being assembled but will be finished for the POF 07 conference. The tracking algorithm has already been implemented successfully, the injection moulded optics is in time.

Discussion

Up to now, no experience with the completed set-up could be gained, but yet there are some items which can still be improved for the next generation:

- More fault tolerant collecting optics with higher concentration ratio (theoretically a factor of 10.000 is achievable but for practical realisation, high precision mechanics is needed leading to costs not acceptable)
- In order to cope with possible deviations of the original adjustment with time, we plan to replace the steering by a sensor assisted control of the solar tracking .

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