SUNLIGHT, FIBRES AND LIQUID OPTICS: THE UFO PROJECT

Mike Wilson[1], Axel Jacobs[1], John Solomon[1], Wilfried Pohl[2], Andreas Zimmermann[2], Aris Tsangrassoulis[3], Marc Fontoynont[4]

[1]*Low Energy Architecture Research Unit (LEARN), University of North London,*
Spring House, 40-44 Holloway Road, London, N7 8JL, UK
Email: m.wilson@unl.ac.uk, a.jacobs@unl.ac.uk, j.solomon@unl.ac.uk
[2]*Bartenbach LichtLabor GmbH, Rinner Strasse 14, A-6071 Aldrans/Innsbruck, AU*
Email: wilfried.pohl@bartenbach.com, andreas.zimmermann@bartenbach.com
[3]*National and Kapodestrian University of Athens, Group of Building Environmental Studies,*
Dept. of Applied Physics, Building Physics 5, 15784 Athens, GR
Email: atsagra@cc.uoa.gr
[4]*Dept. Genie Civil et Batiment URA CNRS 1652, ENTPE, Rue M. Audin F, 69518 Vaulx-en-Velin, FR*
Email: marc.fontoynont@entpe.fr

ABSTRACT

The Universal Fibre Optics project which is part funded by the EC 'ENERGIE' programme involves design and construction of a luminaire which allows the integration of daylight and artificial light. Sunlight is captured through a heliostat and brought into the building by means of a liquid fibre optic cable. Remote artificial backup light is added to maintain the flux output of the luminaire at night and when the sun is obstructed by clouds. The light output at the end of the fibre optic may be described as a cool form of light as both the infra-red and ultra-violet components of the daylight are considerably reduced. Hence the system has a high lumen (of light) to Watt (total energy) ratio resulting in a reduction in the heat load on the AC system. In addition to the prototype system, design guidelines showing the suitability of locations for a variety of sunlight/artificial integrating systems and the principles of integration into buildings will be produced.

KEYWORDS

Fibre optics, liquid optics, remote light sources, sunlight, Fresnel lens, heliostat

INTRODUCTION

The use of sunlight concentrators in buildings is not a new concept. First designs can be traced back the 1930s. Recent developments in fibre optic (FO) technology have made possible much longer run-lengths of the optical cable, enabling the implementation of remote-source lighting and daylighting applications.

The principal problem with using sunlight for interior lighting is that the sun doesn't always shine. Even when it is above the horizon, it might be covered by clouds, rendering the system useless. Traditionally, a daylighting system would also require the installation of an artificial lighting system which it could supplement but not replace. The UFO system incorporates remote artificial light sources. Both, sunlight and artificial light are brought to the luminaire through optical cables. This removes the heat created by the lighting system from the air conditioned space, resulting in a reduced heat load. Because there is no local light generation, no electrical cables need to be run to the luminaire saving the cost of the electrical installation.

COMPONENTS OF THE UFO SYSTEM

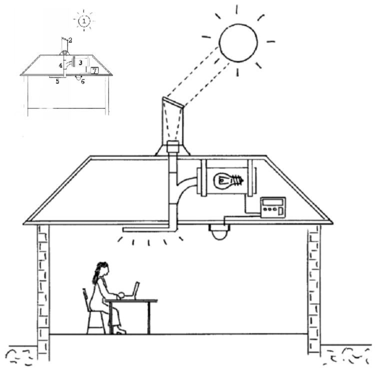

Figure 1: The UFO system and its components

The heliostat

The principle of the heliostat system is based on light captured with a Fresnel lens. The concentrated sun light is coupled into a liquid light guide which transports it to the luminaire. Liquid FO cables have advantages over light tubes because of their much smaller diameter (in the range of a few centimetres) and the almost unrestricted run of the light guide like usual power cables. The Fresnel lens tracks the sun so it is permanently perpendicular to is. This maximises the effective light gathering area. The so-called cosine loss inherent in redirecting solar tracking systems is eliminated.

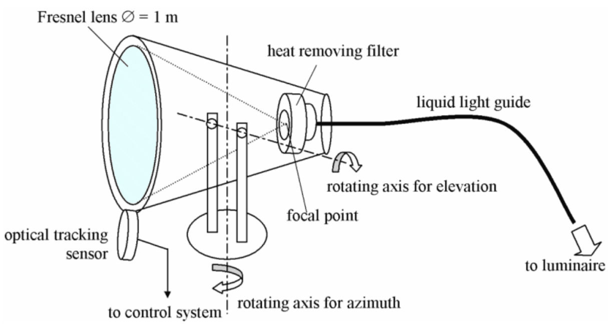

Figure 2: The heliostat

Due to the large portion of infrared radiation in the solar spectrum (nearly half of the total solar radiation is invisible) and the great concentrating power of the Fresnel lens much care has to be taken on the energy/power handling with regard to fire protection and damage thresholds of used components. The most limiting component is the liquid light guide with an excellent transmission in the visible but a strong absorption in the infrared which could lead to blurring or vesication of the transparent liquid core.

Fresnel lens

To capture enough sunlight a lens with a diameter up to 1.0m was necessary. Such dimensions are difficult to realise with glass but possible with the transparent synthetic material PMMA (polymethyl-methacrylate, also known as acryl glass or perspex). Transmission losses in the visible range are negligible with small lens thickness of about a few millimetres, the transmission is only restricted from reflection losses.

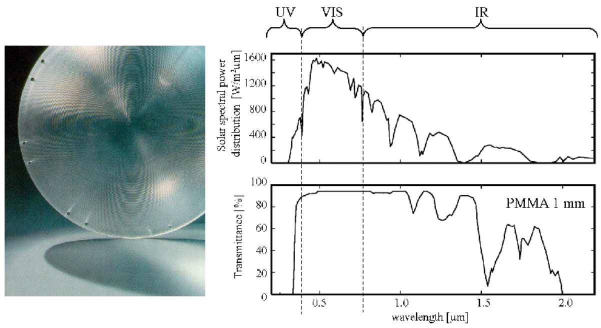

Figure 3: A Fresnel lens with the spectral transmittance properties

Liquid light guide

The light transport in liquid light guides is based on total inner reflections in the liquid core made of a transparent fluid. They are more efficient and less expensive than glass fibre bundles and sealed with glass windows at both ends. Comparable fibre bundles exhibit a smaller acceptance angle and a smaller overall transmittance which is only about half that of a liquid light guide. Even at lengths of up to 30m the spectral distribution of the emitted light is still similar to that of the light source itself and therefore well suited for the light transport over longer distance. There is no undesirable redshift of the spectrum as observed with fibre bundles. At such long distances the total transmission is lowered to 50% (70% at 15m) but still sufficient compared to other systems.

IR-filter

The theoretical image size of the sun is about 1/100 of the focal length but is never reached due to aberrations from the lens. This high energy concentration can cause serious problems with respect to fire hazard and damage thresholds of the light guide. To overcome this problem much of the invisible IR-portion of the solar irradiation must be removed. This can be achieved through the use of a water filter or with a 'hot mirror'.

Control unit

From the geographic position of the heliostat location (latitude and longitude), date and time the actual position of the sun's position can be calculated. This data is used to align the heliostat in the direction to the sun by use of a two-axis motor-driven gimbal mounting. To enhance the tracking accuracy measurements from extern sun position sensors are included in a closed loop control system.

The artificial light source

If a given luminous flux from a hybrid lighting system (sunlight/artificial light) needs to be delivered, the main difficulty stands in the stability of the luminous output of the system. Although for clear days the tracking system allows the collection of a rather stable luminous flux, the passage of clouds may lead to quick and large variation of luminous flux. Although small fluctuations might be desirable, it is in most applications necessary to provide a constant flux output. Very few lamps offer the capability to fully adapt to such variations: fluorescent lamps, halogen lamps and LEDs. Although recent progress in dimming of lamps has been achieved, this dimming does not cover the entire range of output (1 to 100%) and may reduce the life of the lamp itself.

Due to the ready availability of fibre optic projectors, metal halide lamp technology was chosen for the artificial backup lighting. MH lamps have a high luminous efficacy of around 80lm/W. With their small arc length, they can easily be focussed onto a small area such as the common end of the FO cable. In addition to this, their sun-like spectrum makes them ideal for mixing with real sunlight. Unfortunately for the UFO project, fully dimmable MH lamps are not available at this moment in time and are not anticipated to hit the market in the near future. Two projectors as shown in fig. 4 were used which are switched rather than dimmed. Without affecting the lamp life, no more than two on/off cycles per day are recommended. This not only led to a complicated control strategy as explained below, but also meant that additional T5 fluorescent lamps had to be integrated into the luminaire. Once better FO light sources become available, a system with remote-only light sources can be created. This can be done very simply due to the modularity of the components.

Figure 4: A fibre optic projector

The flat panel luminaire

The system was originally anticipated to mix the sunlight and the artificial light in a separate component, a coupler or mixer. However, the research has shown that the overall efficiency of the system will be much improved if the number of junctions will be kept to the absolute minimum. Even with the use of index matching gels, connections make up a significant part of the overall system losses.

It was therefore decided to integrate the mixer into the flat panel emitter. This has the obvious disadvantage of requiring to run two fibres instead of only one, potentially demanding larger bore holes into the room and almost doubling the total length of cables. However, for the sake of a high system efficiency this seemed to be the only sensible solution. The flat panel emitter is a sheet of Perspex material with a white dot pattern screen printed on it. The dots will allow the light which is trapped inside the panel through total inner reflection to break out of the material. By varying the size and distance of the dots, any arbitrary distribution of illuminance across the surface can be created.

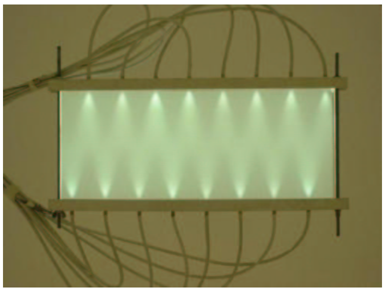

Figure 5: An early prototype of the flat panel emitter

Fig. 5 shows an early prototype of the flat panel emitter. In the final version, all fibres are attached to the short side of the panel, virtually eliminating the scalloping patterns on the surface of the emitter. An optimised dot pattern ensures an even illuminance across the whole of the panel. The flat panel emitter was found to have a high efficiency of between 70 and 90%, depending on the configuration.

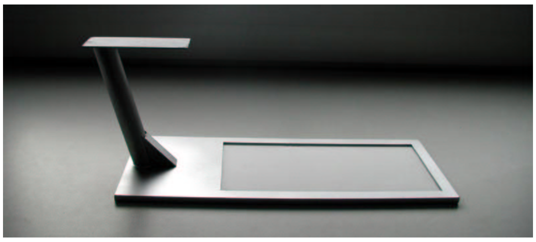

Figure 6: The fibre optic luminaire

Because of the comparatively low lumen output, FO installations have only been applied for task and display lighting. The UFO project is concerned with commercial lighting, so a luminaire was needed that could be used for general purpose lighting, rather than task lighting. An additional requirement was for the fitting to not only enable the feeding in of the FO cables, but also to accommodate of the additional T5 fluorescent lamps. This called for an entirely new design concept. A prototype luminaire is shown in fig. 6.

The controller

The control strategy for the backup lighting is constricted by the following parameters:

- The MH lamps cannot be dimmed without a serious penalty in lamp life and colour
- The heliostat needs direct sunlight to work efficiently.
- The number of switching cycles of the lamps is limited to two per day.

The above mentioned parameters indicate that a commercialised controller cannot be easily introduced, since the efficiency of the whole system basically is depended on the cloud coverage of the sky. In order to avoid unnecessary switching cycles, a prediction of the cloudiness some hours ahead needs to be made. For this, weather information (SKYRON forecasting model) is downloaded twice a day. Automated image analysis enables a forecast of cloudiness to be made, based on the time evolution of the cloud cover. This information is used to switch just one or both lamps on or off. A sketch of the procedure is presented in figure 7.

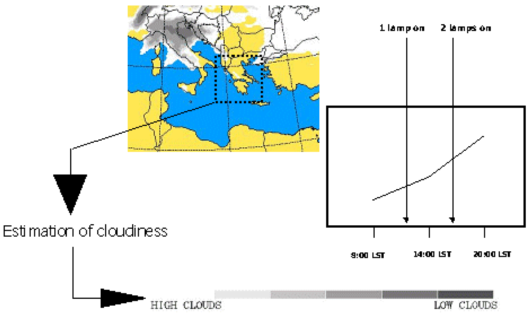

Figure 7: Estimation of cloud cover

THE PILOT INSTALLATION

A pilot installation of a functioning UFO system commenced in June 2002. The site is an office at the University of Athens with a 15m^2 floor area. With an expected peak output of the luminiare of 15,000lm, the expected working plane illuminance directly below the fitting is 800-900lx, while the average illuminance should be just below 400lx. The light delivered through the system has a high luminous efficacy, since most of the heat is dissipated outside the room, resulting in a reduced load to the AC system.

Figure 8: The heliostat being installed at the site of the pilot installation in Athens

The pilot installation was monitored over a period of several months. At the time of this writing, no results were available but it is expected that they can be presented at the EPIC2002 conference.

CONCLUSIONS

The UFO combined artificial/sunlight system provides natural light for non-daylit spaces. The light is transmitted into the space trough fibre optic cables. Due to the variable nature of the sunlight, an artificial lighting system was designed to supplement the sunlight in times when the sun is below the horizon or covered by clouds. Because the artificial light sources are kept outside the room, the cooling load on the AC system is reduced. At present, a powerful and fully dimmable FO projector is not available, so the UFO system also includes local dimmable T5 fluorescent lamps. However, due to the modularity in the design, any component of the system can be very easily replaced when new developments become available on the market.

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