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Creating Sunlight Rooms in Non−Daylit Spaces

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ABSTRACT

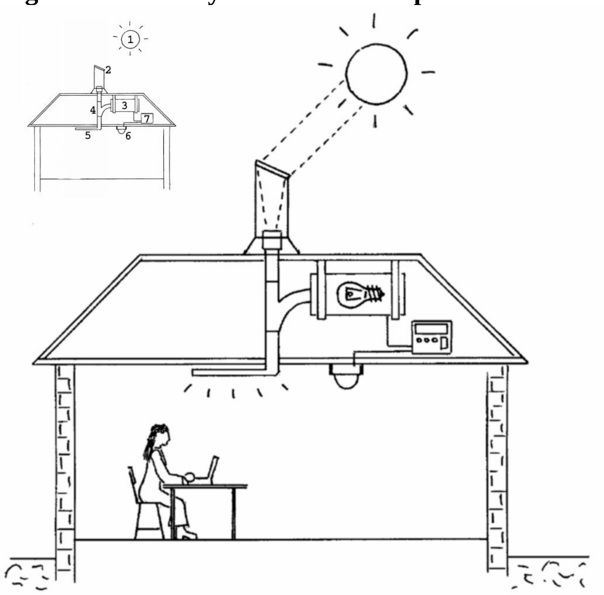
A wide variety of heliostats have been developed over the last 20 years. These allow the focussing of sunlight into a light transmission system for distribution of the light to a part of a building with no access to daylight. This light transmission system may be fibre optics or more recently liquid optics. The distribution of light from a single light source through fibre optics has been available for many years although the system efficiency has been very low and the output restrict to a point source of light. Commonly tungsten halogen sources (inherently of low efficacy) or metal halide lamps have been used. The UFO (Universal Fibre Optics) project part funded by the European Commission Energie programme under contract ERK6−CT−1999−00011, coordinated by the University of North London, has developed a system for the integration of sunlight through a heliostat and liquid optic with an artificial source of light and a fibre optic system. The light from the liquid fibre and from the fibre optic are integrated using a transparent acrylic material with a speckled surface. A prototype system is being demonstrated at the University of Athens during the summer of 2002.

INTRODUCTION

The UFO system consists of a number of individual components. Some of the parts are readily available off−the−shelf, while others are highly innovative and represent entirely new developments in their fields. Care was taken to take a modular approach. This gives the advantage of making it relatively simple and straightforward to accommodate the system to specific buildings and climatic requirements. Another strong point of this concept is that when the state−of−the−art for any of the components moves forward, that particular component can just be replaced with a higher quality or more efficient one, although this is likely to be done only for new installations. The components are (numbers refer to fig. 1) listed below:

- Heliostat (2): Positioned on the roof of the buildings to collect sunlight
- Artificial light sources (3): For times of low sunlight availability
- Fibre optic cables (4): Transmit sunlight and artificial light into the building
- Flat emitter (5): Fed by FO cable, also acts as a mixer for daylight/artificial light
- Control system (7): Turn artificial light off when enough sunlight available

Fig. 1: The UFO system and its components.



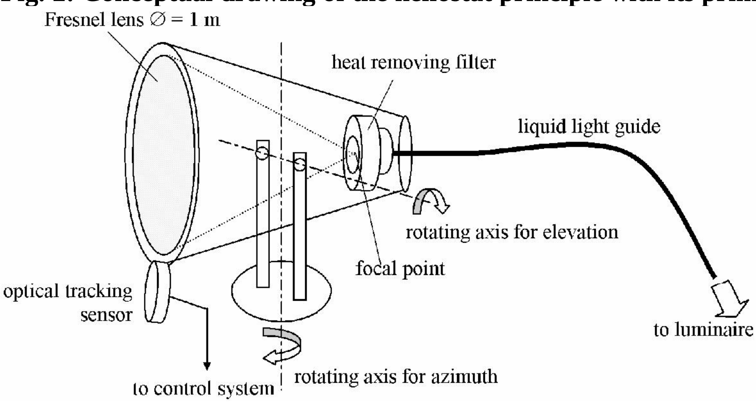
All components are discussed separately in the following paragraphs.

COMPONENTS OF THE UFO SYSTEM

The heliostat

The principle of the heliostat system is based on the light capturing with a Fresnel lens, coupling the concentrated light into a light guide and transporting it via the light guide to the desired place. This has the advantage over the light transport in light tubes because of the small diameter (in the range of a few centimetres) and the almost unrestricted run of the light guide like usual power cables. The Fresnel lens is guided to be permanent perpendicular orientated to the sun so that the effective light gathering area is maximized (the so−called cosine−loss inherent in redirecting solar tracking systems is eliminated).

Fig. 2: Conceptual drawing of the heliostat principle with its prime components



Due to the large portion of infrared radiation in the solar spectrum (nearly the 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 restricting part is the liquid light guide with an excellent transmission in the visible but a strong absorption in the infrared spectral range which could lead to blurring or vesication of the transparent liquid core.

Fresnel lens

To reach a proper amount of captured sunlight a lens with a diameter up to 1.0m is necessary. Such dimensions are difficult to realize with glass but offhand possible with the transparent synthetic material PMMA (polymethyl−methacrylate, also known as acryl glass or perspex). Transmission losses in the visible range are negligible at such small lens thickness of about a few millimetres, the transmission is only restricted from reflection losses.

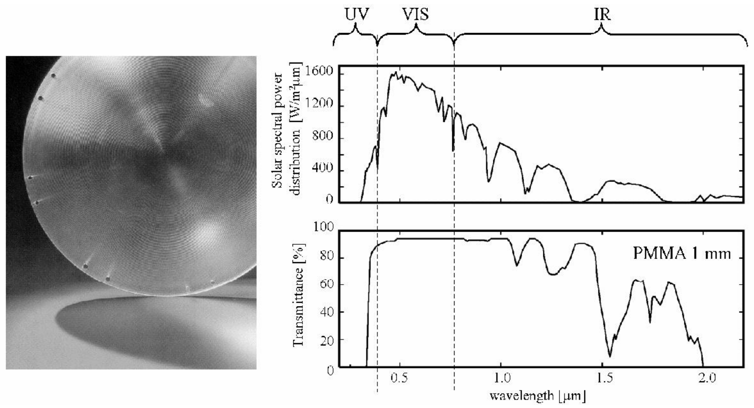
Liquid light guide

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 almost the half of 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 lightsource itself and therefore well suited for the light transport over longer distance. There is also 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 as most as possible of the invisible IR−portion of the solar irradiation which accounts for nearly the half of the total solar irradiation must be removed. This can result from absorption in a water filter or due to specific IR−reflection on a ’hot mirror’.

Fig. 3: left: A Fresnel lens made of transparent PMMA with its typical concentric groves, right, top: spectral power distribution of the global solar irradiation, bottom: transmittance characteristic of PMMA



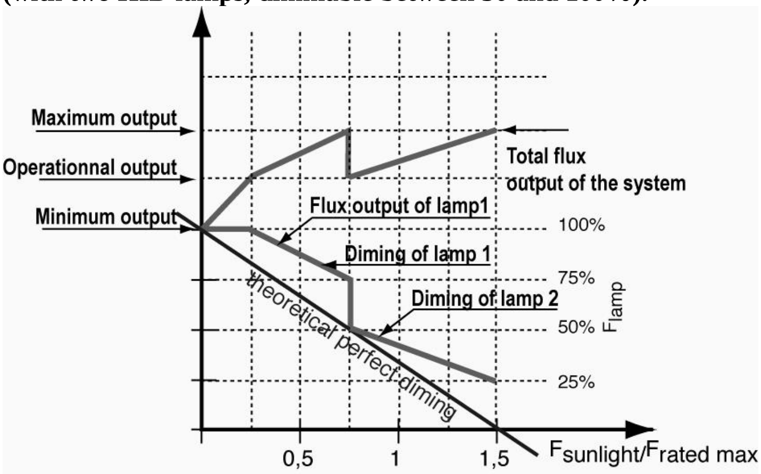
Control unit

From the geographic position of the heliostat location (latitude and longitude), date and time the actual position of the sun relative to the heliostat 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 one aims at supplying a given luminous flux from a hybrid lighting system (sunlight/artificial light), 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, passage of clouds may lead to quick and large variation of luminous flux. 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.

Fig. 4: Variations of light output from the generator as a function of the incoming sunlight (with two HID lamps, dimmable between 50 and 100%).



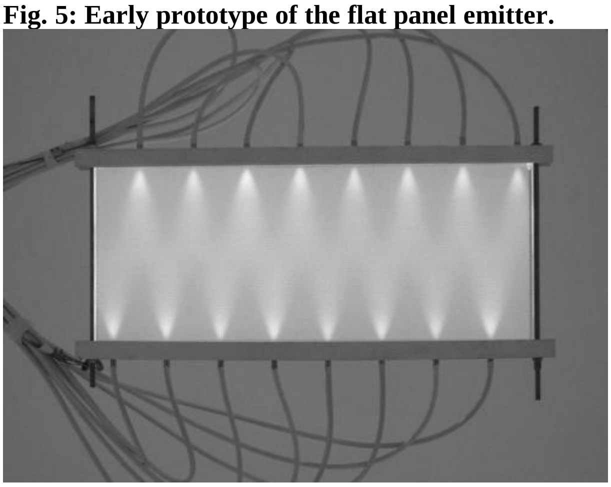
Hence the need to accept variations in the flux output of the system, within an acceptable range. For this reason, we have selected the Metal Halide technology. HID lamp have a high luminous efficacy (above 80lm/W) and a spectrum which make some of them suitable for indoor lighting. Recent developments have demonstrated that these lamps can be dimmed from 100 to 50% without hurting the lamps. The professionals foresee dimming below 40% in 2003−2004. For our application, and in order to offer a wide range of flux output, we propose to use two generators, with two dimmable HID lamps. This will allow the supply of all flux values between 25 and 100%.

Because every optical coupling between filter option or between filter option and liquid fibre optics leads to substantial losses, it was decided that the FO system will connect directly the generator to the luminaire system.

The flat panel emitter

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.

Fig. 5: Early prototype of the flat panel emitter.



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 requiring larger bore holes into the room and almost doubling the totla 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 reflectio to break out. By varying the size and distance of the dots, any arbitrary distribution of illuminance accross the surface can be created.

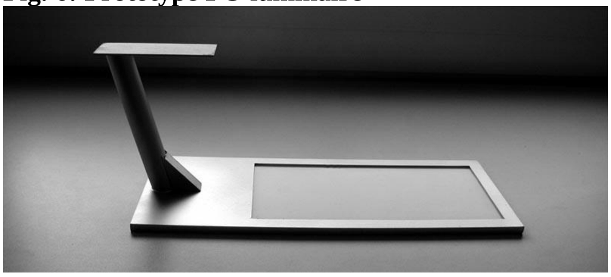
Fig. 5 shows an early prototype of the flat panel emitter. In the final version, all fibres will be attached to the short side of the panel, virtually eliminating the scalloping patterns on the surface of the emitter. An optimised dot pattern will ensure an even illuminance across the whole panel.

The flat panel emitter was found to have a high efficiency of between 70 and 90%, depending on the configuration. This was determined by comparing the light output from the emitter with the output of the bare ends of the FO cable as measured in an integrating sphere.

The end of FO cables can be considered a point source with a certain beam angle which depends on the type of transmission material. In typical FO installations, a fixture is usually attached to the fibre end in order to modify the distribution or make for an attractive fitting. Because of the low lumen output, FO installations so far have only been applied for task and display lighting.

The UFO project is concerned with office 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.

Fig. 6: Prototype FO luminaire



Because of the problems with the dimming of metal halide lamps, a compromise had to be made to allow for the immediate response of the system to changing external light conditions. MH lamps can not be fully dimmed, and switching them more than twice a day will dramatically reduce their life expectancy. Additional T5 lamps are therefore included in the fitting. Their light is coupled into the flat emitter, so the actual source of the light will not be apparent to an observer.

The controls

The control strategy that will be used is constricted by the following parameters:

- The ballasts cannot dim the metal halide lamps 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 in rather limited

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. Is it possible to measure cloudiness real time? A possible approach is to take a fish−eye digital picture of the sky. After some analysis the cloud coverage can be estimated. Another method is to use global and diffuse horizontal radiation measurements in order to estimate the clearness factor according to Perez model. Nevertheless although cloudiness can be measured, the rest of the system cannot compensate.

Thus, basic information on how the sky will be some hours ahead is needed. This calls for a weather forecast. The system under development is presented in fig. 7.

Weather info (SKYRON forecasting model) is transmitted twice a day via FTP. The image concerning the forecast of cloudiness is analysed and based on the time evolution of the cloud cover (in conjunction with rain). A decision is made whether one or both lamps should be switched on or off. A sketch of the procedure is presented in the figure below:

Fig. 7: Basic layout of the control system

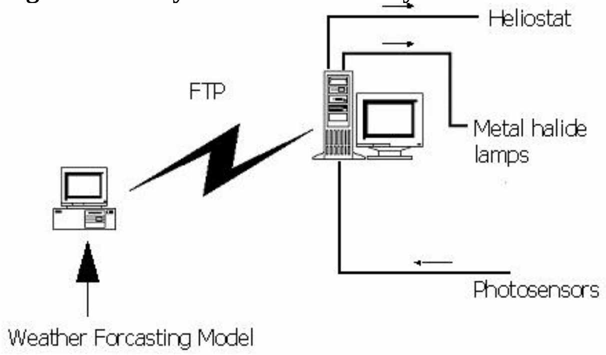
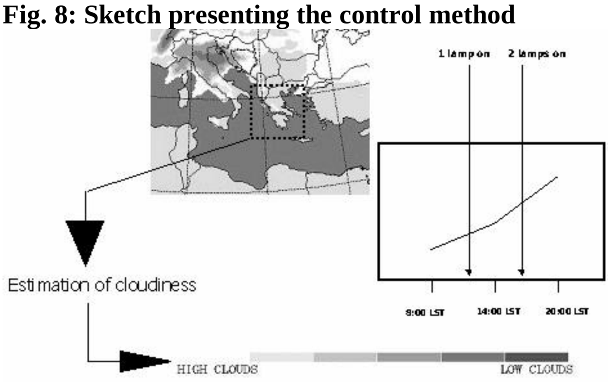


Fig. 8: Sketch presenting the control method



THE PILOT INSTALLATION

The pilot installation will be made in an office at the University of Athens. The floor area which is to be lit will be 15m2. With a 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. This light will have a very high luminous efficacy, since most of the heat is dissipated outside the room, resulting in a reduced load to the AC system.

The pilot installation will be monitored over a period of several months. First results are expected by the end of the summer of 2002.

CONCLUSIONS

The UFO combined artificial/sunlight system is aiming to provide 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 aritificial 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.

REFERENCES

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