# LUMINOUS PERFORMANCE AND ENERGY SAVINGS OF A SOLAR TRACKING MIRROR SYSTEM FOR DAYLIGHTING

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## ABSTRACT

The aim of the present study is the proposal of a novel tracking mirror system for the daylighting of deep interior spaces, such as commercial buildings, underground railway stations, parkings, etc.. The analytical approach demonstrates that it is possible to supply an acceptable workplane illuminance for 6/8 hours per day during the year in southern Italy. The experimental data, obtained by means of a physical model, support the theoretical analysis. Benefits in terms of energy savings and illuminance level, especially in clear sky conditions, are outlined.

## KEYWORDS

Daylighting, tracking devices, mirrors, light-pipes, underground buildings

## INTRODUCTION

The project and the development of underground areas are often an important and difficult task of the urban design of a modern town. The design of such spaces is aimed at the achievement of the environmental comfort. The indoor climate conditions have to be checked carefully: the values of the internal temperature and humidity, the artificial ventilation, the illuminance level have to guarantee an acceptable comfort level. Generally adequate technical solutions are requested for this purpose.

In this study a novel dynamic system is proposed in order to daylight deep interior spaces. Indeed the lack of natural light for a long period causes physiological and psychological problems, whereas the natural light improves the visual comfort and the pleasantness of the environment. If correctly used, daylighting can reduce the thermal loads and the artificial lighting costs.

## SYSTEM DESCRIPTION

The proposed system (fig.1) is composed by:

- rectangular flat mirrors, fixed perpendicularly to square structures of support (fig.2); these structures, located on a skylight passage, can rotate in altitude and azimuth following the apparent motion of the sun. The movements were settled in such a way that the beams reflected by the mirrors were vertical and directed downwards;

- flat fixed mirrors in the skylight passage, located at the level of the windows of each floor (fig.3); the tilt angle of these mirrors and their mutual position were settled in order to illuminate the ceilings of the building and to avoid any interference;
- white and smooth reflective ceilings, able to diffuse the light onto the workplane.

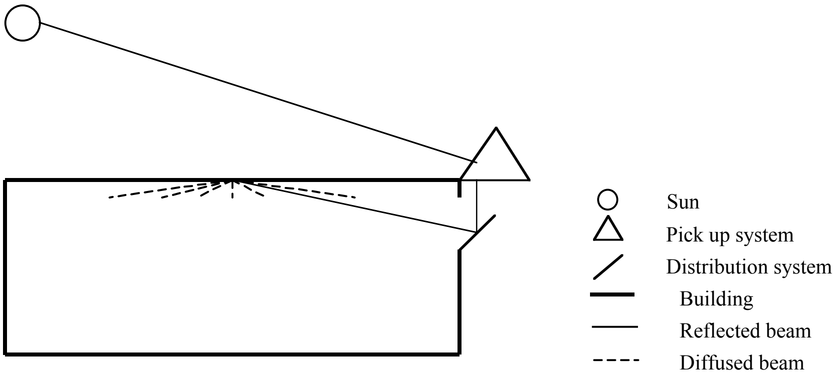


Figure 1: The proposed system

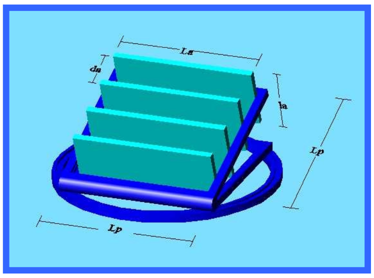


Figure 2: the pick up system

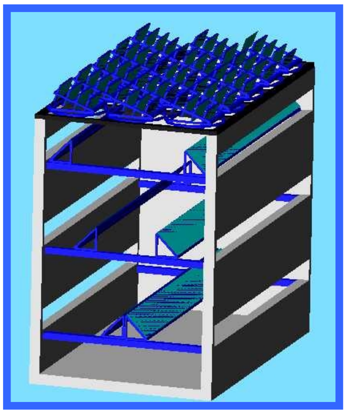


Figure 3: The skylight passage

## LUMINOUS PERFORMANCES

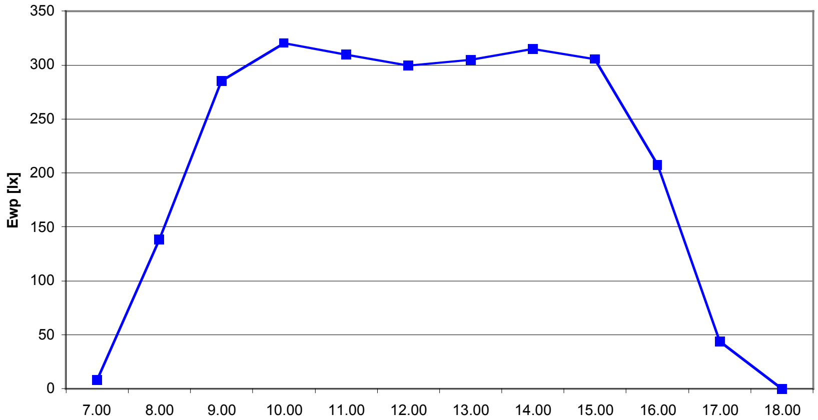
An analytical model of the proposed system is detailed in [Sicurella, 2000]. The results of this analysis are in good agreement with the experimental data based on a physical model [Sicurella, 2000].

As shown in a previous paper [Carbonari et al., 2001] the proposed system can offer a satisfactory luminous performance: the average hourly illuminance levels on the workplane during the year in Catania (Lat.37.5N, Long.15E), for ten working hours (8.00-18.00), are shown in table 1.

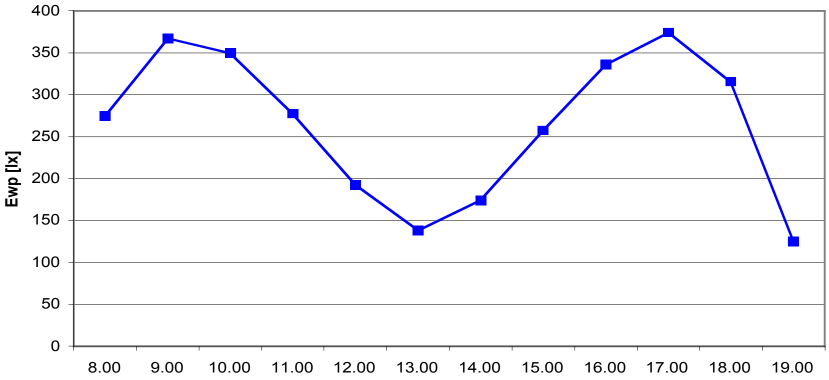
The illuminance levels for four typical days are shown in figure 4.

TABLE 1
Average hourly illuminance level

| **Month** | January | February | March | April | May | June | July | August | September | October | November | December |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Ewp [lux]** | 195 | 225 | 250 | 260 | 275 | 280 | 290 | 300 | 280 | 240 | 210 | 185 |



15th march



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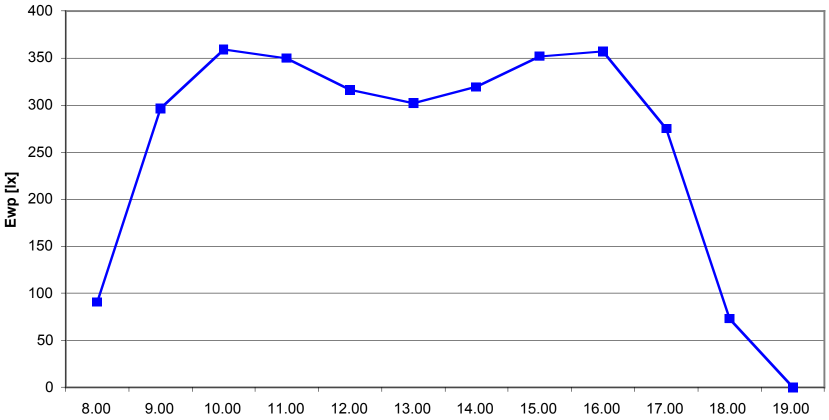
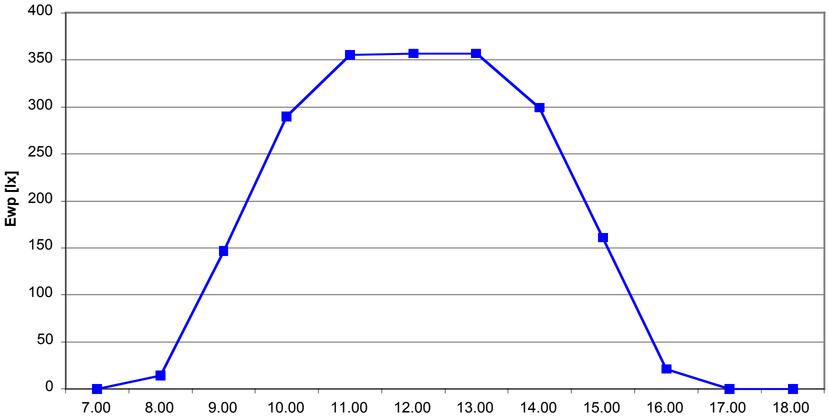


15th september



15th december

Figure 4: Illuminance levels for four typical days

## ENERGY ANALYSIS

A comparison of the yearly energy costs for the artificial lighting devices with and without the proposed system is made by considering a department store building of 1680 $m^2$ with a required average illuminance as high as 500 lux onto the workplane for hours per day (8.00-18.00) excluding holidays.

The artificial lighting system is supposed to be made of 288 couples of 36W -fluorescent lamps of 3350lm each, with a total flux of 1929.6klm. In order to reach the fixed illuminace target, a dimming device guarantees a continuous control of the flux aiming at regulating the artificial light following the natural light availability.

The instantaneous flux to obtain the required illuminance level $E_{req}$ is evaluated by the formula:

$$\phi(\tau) = \frac{E_{req.} - E_{syst.}(\tau) \cdot SSP(\tau)}{C_u} \cdot A$$

where:

$\phi(\tau)$ is the real instantaneous flux emitted by the lamps

$E_{req}$ is the required illuminance target

$E_{syst.}$ is the instantaneous illuminace level guaranteed by the daylighting system [Sicurella, 2000]

SSP is the sunshine probability function

A is the horizontal surface area hit by the natural light

$C_u$ is the coefficient of utilisation of the lamps

The hourly sunshine probability function of the site was calcutated according to the Szerman method [Szerman et al., 1996] as a function of:

- geographical data (latitude, longitude and altitude of the site, time zone)
- optical data (ground reflection index)
- atmospheric data (atmospheric turbidity, average monthly raining water)

The average monthly rain water is calculated by the formula [Vio, 1996]:

$$O_w = 0.493 \cdot \frac{U_r}{T + 273.15} \cdot e^{26,3 - \frac{5416}{T+273,15}}$$

where:

$O_w$ is the average monthly rain water

$U_r$ is the relative humidity

T is the dry bulb temperature

These two last entries refer to a reference year for the specific site; concerning the turbidity, an average monthly value for urban areas was considered [Hitchcock et al., 1996]

Consequently it was possible to determine the instantaneous dimming of the artificial lighting system by the formula:

$$\mathrm{Dim}(\tau) = \frac{\phi(\tau)}{\phi_{tot.}}$$

where:

$\phi(\tau)$ is the instantaneous flux emitted by the lamps

$\phi_{tot}$ is the installed total flux

The effective power absorbed by the lamps was calculated on the basis the manifacturer's data, as a percentage of the total illuminating power installed (table2).

TABLE 2

The average monthly dimming and the percentage of the total illuminating power installed

| **Month** | January | February | March | April | May | June | July | August | September | October | November | December |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Dim.** | 0,73 | 0,72 | 0,67 | 0,59 | 0,51 | 0,49 | 0,46 | 0,39 | 0,54 | 0,71 | 0,7 | 0,85 |
| $\beta$ | 0,76 | 0,74 | 0,7 | 0,64 | 0,56 | 0,55 | 0,52 | 0,47 | 0,6 | 0,74 | 0,73 | 0,88 |

## Energy Savings

The achieved energy savings is given by the formula:

$$S = C_{el}(art.) - C_{el}(syst.) \qquad [kWh]$$

where:

$$C_{el}(art.) = P_{tot.} \cdot n_{wh} \qquad [kWh]$$

is the electrical energy consumption of the artificial system without the proposed system;

$$C_{el}(syst.) = \beta \cdot P_{tot.} \cdot n_{wh} \qquad [kWh]$$

is the electrical energy consumption of the artificial system with the proposed system;

$$P_{tot.} = n_l \cdot P_{max}$$

$n_{wh}$ is the number of working hours;

$n_l$ is the number of couples of lamps

$P_{max}$ is the power absorbed by a couple of lamps and one reactor.

Figure 5 and table 3 show the results.

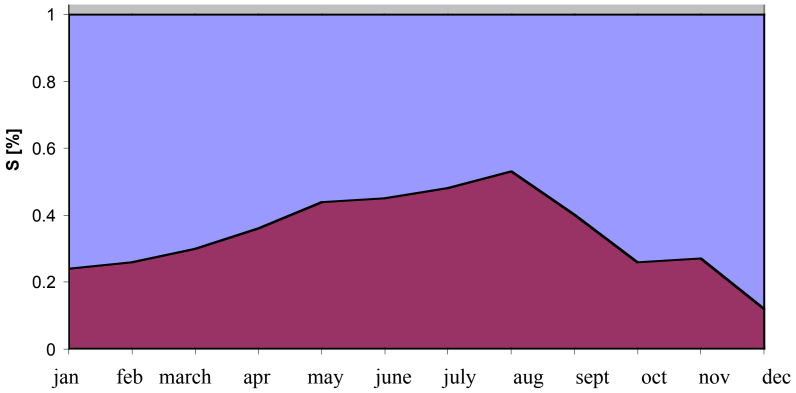


Figure 5: energy savings

TABLE 3
Result of the energy analysis

| **Month** | $n_{wh}$ | $P_{max}$ **[W]** | $n_l$ | $P_{tot.}$ **[W]** | **Cel(art.) [kWh]** | **Cel(syst.) [kWh]** | **Savings[kWh]** | **Savings [%]** |
|---|---|---|---|---|---|---|---|---|
| January | 220 | 108,5 | 288 | 31248 | 6874,56 | 5225 | 1650 | 0,24 |
| February | 200 | 108,5 | 288 | 31248 | 6249,6 | 4625 | 1625 | 0,26 |
| March | 220 | 108,5 | 288 | 31248 | 6874,56 | 4812 | 2062 | 0,30 |
| April | 200 | 108,5 | 288 | 31248 | 6249,6 | 4000 | 2250 | 0,36 |
| May | 220 | 108,5 | 288 | 31248 | 6874,56 | 3850 | 3025 | 0,44 |
| June | 210 | 108,5 | 288 | 31248 | 6562,08 | 3609 | 2953 | 0,45 |
| July | 220 | 108,5 | 288 | 31248 | 6874,56 | 3575 | 3300 | 0,48 |
| August | 220 | 108,5 | 288 | 31248 | 6874,56 | 3231 | 3644 | 0,53 |
| September | 200 | 108,5 | 288 | 31248 | 6249,6 | 3750 | 2500 | 0,40 |
| October | 240 | 108,5 | 288 | 31248 | 7499,52 | 5550 | 1950 | 0,26 |
| November | 210 | 108,5 | 288 | 31248 | 6562,08 | 4790 | 1772 | 0,27 |
| December | 190 | 108,5 | 288 | 31248 | 5937,12 | 5225 | 712 | 0,12 |
| **Total 2001** | 2550 | 108,5 | 288 | 31248 | **79682,4** | **52240** | **27442** | **0,34** |

## CONCLUSIONS

In this study a novel dynamic daylighting system was proposed in order to increase the comfort of underground buildings and achieve significant energy savings in terms of artificial lighting consumption.

The analytical approach, supported by experimental data, demonstrates that the proposed system can offer a satisfactory performance (200 lux and more) for 6/8 hours per day during the year in southern Italy.

The energy analysis shows that the use of this system can reduce the energy costs for artificial lighting up to 50%. For an extensive use of the system (10 hours per day) the yearly average energy savings is 34%. Even higher energy savings could be obtained if the daylighting system is adopted in less severe conditions (e.g. 9.00-16.00).
This novel tracking mirror system could be employed in all sites characterized by clear sky for a great part of the year (e.g. in developing countries).

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