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# Daylight Optimization of Buildings and Application of Advanced Daylighting Systems in Central Mexico

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## Abstract

The intensive use of daylight in buildings is beneficial at many levels: it provides sufficient levels of illumination to perform working activities throughout the day and it reduces the use of artificial light, which in turn leads to lower electricity consumption [1-3]. The spectral composition of daylight often leads to higher visual comfort in humans, compared to electric lighting. There are also illuminance and spectrally-dependent light effects on the human circadian system, which regulate hormonal rhythms, alertness and (visual) performance across 24 hours [4-6]. The main objective of this work was to assess luminous performance in office buildings and to test optimizations by virtually applying different daylighting strategies by computer simulations.

We first assessed the daylight distribution in two different office rooms, set-up as test modules on the EPFL campus in Lausanne (46° 32'N, 6° 39'E). One of these test modules is equipped with a standard double-glazing; the second one comprises anidolic daylighting systems [7], which convey diffuse daylight and sunlight deeper in the room, and reduce glare risk. In both rooms, we also assessed vertical spectral irradiance in the visible range, which gave us additional information with respect to photo biological properties of the available daylight. We then measured the real daylighting situation in an office room located in the city of Zacatecas, Mexico (22°47'N 102°34'W), which is equipped with a standard double-glazing window. In a next step we tested, whether the daylight distribution for this room could be improved by virtually applying different complex fenestration systems (such as prismatic panels and laser cut panels) by using computer simulations. The results of these simulations showed higher indoor luminous performance with the two advanced daylighting systems. This new method may contribute to an improved and tailored design of daylight availability in real buildings at different geographical locations.

## Introduction

Daylight in buildings often leads to benefits for energy efficiency and to positive effects on visual and non-visual functions in humans. Because of these benefits the efficient use of daylight has become more relevant recently [2]. Many strategies have been developed to effectively use this natural light source, including the development of advanced daylighting systems. Their common principle is the efficient collection of the exterior daylight (direct and indirect components) its redirection into the interior space and thereby improvement of light distribution in the room [7]. One of the main characteristics of daylight is its temporal variation caused by meteorological and seasonal parameters [8] and therefore, different types of advanced daylight systems were designed to fit the geographical location of a building. For example, at locations with predominantly overcast weather conditions, the main task of the advanced daylighting system is to collect and redistribute the diffuse daylight component inside the room. Different advanced daylighting systems, based on non-imaging optics (anidolic systems), were developed for this purpose. The physical principle of these non-imaging optics systems is an angular selection of the admitted light rays with a minimal number of inter-reflections so that the system efficiently collects diffuse daylight from the sky vault and re-distributes it in the interior space [7]. In the case of locations with predominantly clear sky conditions, the objective is not only to collect and re-distribute the daylight indoors but also to protect from the incidence of direct sunrays and to avoid overheating and the risk of discomfort glare. Therefore, for locations at low geographical latitudes different solutions are required and only few advanced systems have been implemented so far [9].

One of the objectives of this work was to analyse the performance of an already implemented advanced daylighting system in a real size test room, and to compare the distribution of daylight to a second test room with standard double glazing windows in Switzerland. A second aim was to evaluate the lui nous performance at low latitude locations with prevailing clear sky conditions (Zacatecas, Mexico 22°47'N 102°34'W). We finally simulated the efficiency of different complex fenestration systems (CFS) by using ray tracing simulation methods (Radiance-based, [10]). For the CFS, we used a laser-cut panel and a prismatic panel, which are recommended for prevailing clear sky conditions [2].

## METHODOLOGY

### 1. Assessment of daylight availability in two test modules (with and without advanced daylighting systems)

The two test modules are located on the EPFL campus in Lausanne, Switzerland (46°32'N, 6°39'E Altitude: 410 m), with an equal size of 3.05 x 6.55 x 3.05 m and south orientated windows. One of these two modules is equipped with a standard double glazing window and serves as reference room, while the second module contains two different anidolic daylighting systems (ADS): an anidolic ceiling (AC) and an integrated anidolic system (IAS) [11]. Both modules have identical photometrical and geometrical features (Figures 1 and 2). For this work, we have chosen to compare the IAS to the standard double glazing window, because of its lower cost and presumably easier adaptation for potential building retrofits in México.

*Fig.1 Outside view of the two test modules on the EPFL campus. The test module on the left side contains integrated anidolic systems (IAS) and the test module on the right side is equipped with a standard glazing window.*

*Fig.2 Interior view of the standard double glazing module at the EPFL campus (Switzerland).*

In order to better understand the advantages of the IAS vs. the glazing system in the reference room, we conducted on-site monitoring: We first assessed the daylight distribution in both test modules by calculating their daylight factors (DF). The DF is defined as the ratio of indoor illuminance on a horizontal surface ($E_i$) and the simultaneously available outdoor iluminance ($E_o$) by using the formula: DF=($E_i$/$E_o$) x100 (%). [11, 12]. To account for the non-visual aspects of daylight, we also assessed the vertical C($\lambda$)-weighted spectral irradiance [13] in the blue range of the visible light spectrum, using a portable digital spectroradiometer (Specbos 1201, JETI Technische Instrumente GmbH, Jena, Germany). The spectroradiometer was placed in the centre of the room, by directing the device on a vertical plane to the wall at 1.2 m height (i.e. at the approximate eye level of a sitting person). Measurements were taken every 15 minutes, alternating for both modules from 9am until 6pm, under intermediate sky conditions.

### 2. Luminous performance assessment in an office without advanced daylighting systems at a different geographical latitude

We selected an existing building in the city of Zacatecas, Mexico (22°47'N 102°34'W) and assessed its real luminous performance by performing illuminance and luminance measurements. We used two different illuminance meters (Chauvin Arnoux C.A. 811 Lightmeter) for interior and exterior measurements, which had prior been referenced to a calibrated device (Spectroradiometer, Specbos 1201, JETI Technische Instrumente GmbH Jena, Germany). For luminance measurements we used a special customized device made of a tube with an aperture of 3° (diameter of opening= 2 cm) covered inside with a black foil and placed on the illuminance sensor; the calibration of this device was made by using a luminance meter as reference (LS-110 Minolta).

The selected room was the Library's office of a private educational University (Tecnologico de Monterrey campus Zacatecas, México). The room showed poor availability of daylight due to the very low glazing transmittance of the tinted glass (31%) and a South-West orientation of the building. Two pictures taken at imes of day show the interior view of the Library's office in the morning (Figure 3) and in the evening hours (with direct sun shining on the working area; Figure 4).

*Fig. 3. View of the Library's office under overcast sky conditions in the morning*

*Fig. 4. View of the Library's office under clear sky conditions in the evening*

In order to perform a detailed analysis of the real luminous performance in the office showed on Figure 3 and 4, we carried out measurements under overcast and clear sky conditions, using the DF as a metric to assess the indoor daylight distribution.

### 3. Luminous performance optimization for an office with poor daylight availability

The optimization of daylight availability in buildings requires a strategy which includes early decisions in the architectural design, such as interior material properties, window configuration and glazing transmittance as well as the use of CFS. Different combinations of these previously mentioned parameters were virtually assessed and tested by using computer simulations, based on ray tracing software (Radiance [10]). In order to simulate the implementation of two different CFS [14], we used existing BTDF data (Bi-directional Transmittance Distribution Function[15]). Simulations with two different CFS, laser-cut panel and prismatic panels (3M Optical Lighting Film), were performed.

## RESULTS

### 1. Assessment of daylight availability in two test modules

Overall, there was a significant difference of the DF's between both test modules ($p<0.05$). Morevover, the DF in in the middle of the room of the reference test module was only 2.5%, but 4% for the module equipped with the IAS, which suggests a different light distribution deeper in the room (Figure 5).

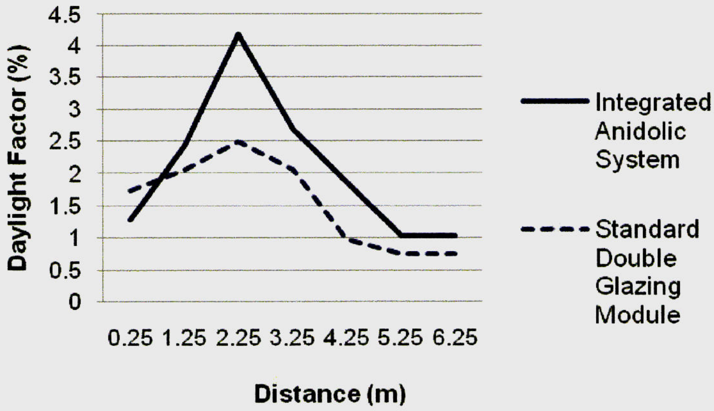


*Fig. 5 Daylight Factor (%) in the test modules with the integrated anidolic system and the standard room.*

The vertically C(λ)-weighted spectral irradiance of the visible light spectrum was significantly higher in the module with IAS compared to the reference test room with standard double glazed window (1.295 W/ m² vs. 0.5089 W m²; $p<0.05$, Figure 6).

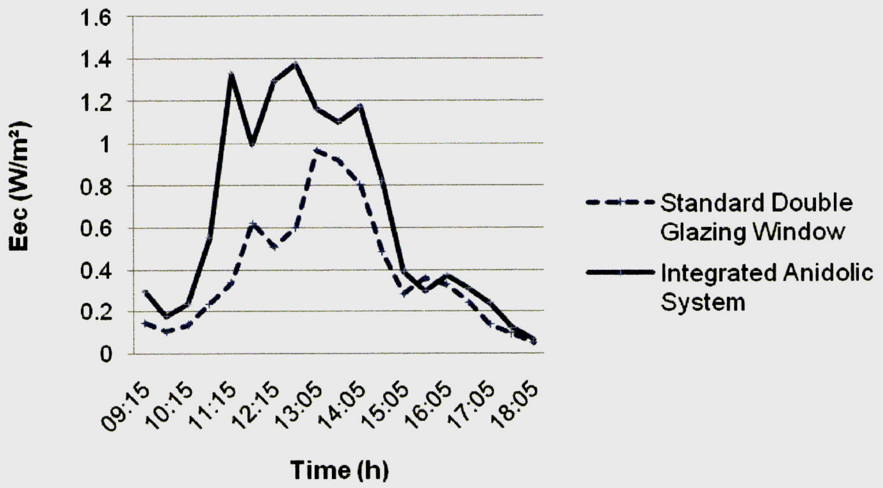


*Fig.6. Spectral irradiance ($W/m^2$), measured in a vertical direction from the centre of the two test modules, across different times of day.*

## 2. Luminous performance assessment in a real office without advanced daylighting systems

The calculation of the DF in the Library Office in México showed a rapid decrease deeper in the room. Starting with a DF of 5.9% at a distance of 0.4 m from the window, the DF gradually decreased and was only 0.9% in the back of the room (Figure 7). The luminance measurements further showed low levels and inadequate luminance-ratios between paper tasks, screen and walls, as well as a high contrast between the window and the surrounding areas (data not shown). These on-site measurements were used to compare the optimization strategies which we carried out with computer simulations.

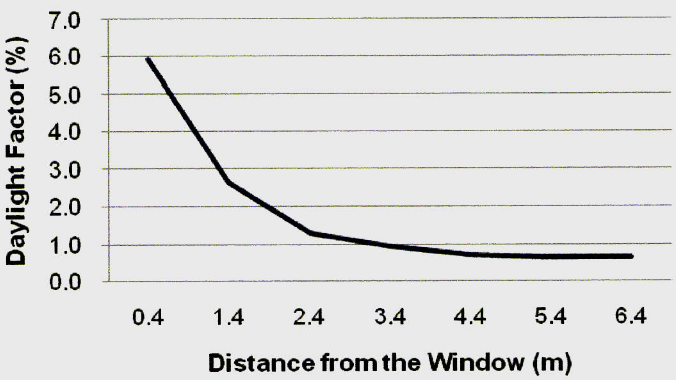


*Fig.7. Daylight Factor measurements in the Library Office, México (measurements were taken every m)*

## 3. Daylight simulation of a real office with and without complex fenestration systems

Figure 8 illustrates the simulated Library's office room situation in México, where we measured in average a minimum illuminance of 926 lx. After increasing the transmittance of the glazing up to 80% (Figure 9), the same room showed a minimum illuminance of 3451 lx. When we virtually applied a prismatic panel, a minimum illuminance of 3531 lx (Figure 10) was obtained, and with a laser-cut panel we reached a minimum illuminance of 3540 lx (Figure 11); all simulations were carried-out using BTDF data.

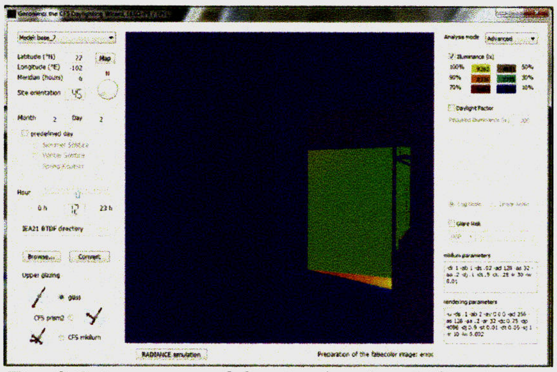

*Fig. 8 Print screen of the simulated real illuminance situation in the office in Mexico, with South-West orientation of the building and a glazing transmittance of 31%.*

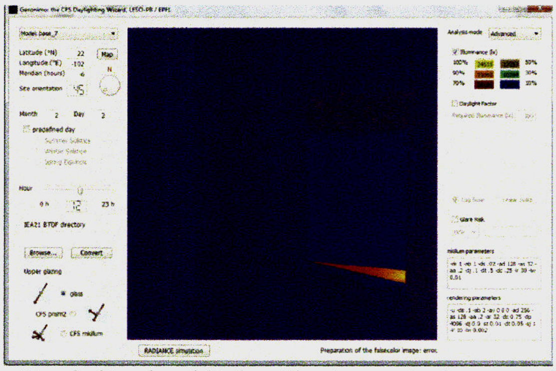

*Fig. 9. Simulated higher illuminance in the same office room in Mexico when the glazing transmittance was increased to 80% (South-West orientation).*

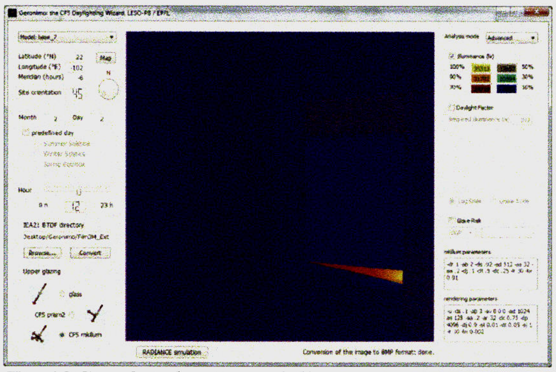

*Fig.10.Simulated optimized illuminance situation by using a prismatic panel as a complex fenestration system (South-West orientation; Film 3M interior)*

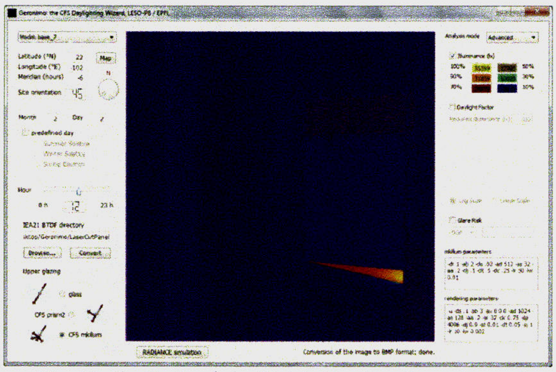

*Fig.11. Optimized daylight situation by using a laser-cut panel as a complex fenestration system (South-West orientation).*

## DISCUSSION

We assessed the real daylighting situation by monitoring the daylight factor in two test modules in Switzerland and in an office room in Mexico. For the two test modules in Switzerland, we found a slightly better daylight distribution in the module equipped with the IAS, when compared to the module with the standard double-glazing window. The C(λ)-weighted spectral irradiance in the blue range of the visible spectrum was significantly higher in the module with the IAS, suggesting that the interior daylighting environment may be beneficial not only in terms of energy savings but also for visual and non-visual human functions. We also showed by computer simulations that the luminous daylight performance could be improved in real office rooms at low geographical latitudes (library office in México) by using different complex fenestration systems. Further studies are needed to investigate different daylighting metrics in order to also include time of day and year, weather conditions and local climates [16]. Future work should also address problems related to discomfort glare and thermal comfort, in order to avoid potential overheating due to excessive solar gains - both are non-negligible risks for buildings located at low geographical latitudes. To summarize, our results showed possible improvements for indoor daylight performance by virtual application of advanced daylighting systems, using computer simulations. This might be used to improve daylight performance in the design of new buildings or the retrofit of existing buildings at low geographical latitudes.

## ACKNOWLEDGEMENTS

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