DAYLIGHTING IN SUSTAINABLE INTERIOR DESIGN OF OFFICES

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Received: 21.09.2015; Revised: 19.01.2016; Accepted: 3.11.2016

Abstract
The paper presents issues concerning realization of paradigm of sustainable design in the architectural design of offices. Special attention is given to relevant technical, formal and functional solutions, being the domain of interior architects creating the built environments of adequate indoor quality with substantial reduction of negative impact on natural environment. Presented sustainable architectural interiors, completed in the last decade, have gained certificates established by independent scientific institutions, assuring their accordance with exigencies of rating systems. The paper analyzes the formal methods of proper space planning, which assure high indoor environment quality parameters for the end users of office interiors in terms of optimum daylighting of workstations and recreational areas as well as workers' visual contact with natural valuable surroundings. These requirements can be satisfactorily met by properly shaped inner space elements including partitions, ceilings, space-dividing structures as well as rational and effective use of finishing and building materials. Technical and technological devices incorporated into the inner space mentioned in the paper are supposed to be essential complement of these design methods assuring proper daylight transmission and distribution in workspaces. Discussed examples indicate the necessity of collaboration of interior architects with other professionals and consultants (i.e. green building accredited consultants), whose design contributions should be accepted and respected. Integrated interior design process assured fulfillment of imperatives for sustainable architectural design of interiors.

Keywords: Interior design; Built environment; Rating Systems; Multicriterional Evaluation; Daylighting; Indoor Environment Quality IEQ; Passive solar optic systems PSO; Visual comfort.
1. INTRODUCTION

The imperatives of sustainable architectural design require that contemporary interior designers propose solutions concerning not only functional, spatial and aesthetic problems of inner spaces creation. They should equally consider questions of minimizing the negative impact of man-made environment on the natural one, the necessity of indoor environment quality enhancement and occupants’ comfort optimization in accordance with environmentally responsible interior design (ERID) strategy [1]. These complex exigencies imposed on design aspects should not dominate, but become an integral part of every project concerning the creation of inner spaces [2]. Multi-criterional evaluation, based on the parametrical assessment of building’s energy saving-, proecological- and social- oriented solutions, being one of the contemporary professional design tool, is considered by many researchers and practitioners as a method of reliable verification of sustainability of the built environment. The Leadership of Energy and Environmental Design for Commercial Interiors (LEED-CI) internationally recognized green building rating system, developed and launched by the United States Green Building Council (USGBC) in 2004, is one of the few certification systems dedicated to environmental evaluation of commercial interiors, commonly applied by architects and developers. In its revised version LEED for Interior Design and Construction (LEED ID+C) v4, put in effect in June 2015, within Indoor Environment Quality (IEG) system core category, there is a credit concerning daylighting criterion, which allows to assess the space’s daylight autonomy and its proper sunlight exposure [3].

Advantegous daylighting is one of the most important parameters of interior quality, and a substantial factor of physiological stimulation and regulation of circadian rhythm in office spaces. It remains essential in creating users’ comfort. Rational distribution of daylight in inner spaces, in consequence of cohesive design, substantially reduces energy demands for the built environment. It enhances energy efficiency and optimizes operational costs through the reduction of possible expenditure due to the use of artificial light. This is achieved by the extensive daylight penetration within inner spaces along with implementation of artificial lighting control devices and energy-effective equipment. All these measures allow the accomplishment of sustainability paradigm, in social, ecological and economical aspects of architectural design.

2. DAYLIGHTING IN OFFICES

The adequate daylighting in contemporary working environment is one of the most important parameters recognized as making a significant impact on the physical condition of office employees. The health problems related to deficiency of daylight are caused by so called Seasonal Affective Disorder and the psychological discomfort of interiors’ users. Sustainable design of social-oriented and energy-efficient interiors, allowing for the enhancement of daylighting in offices, has led in consequences to the improvement of conditions in working areas to users’ visual comfort and multifunctional usage of auxiliary spaces. It resulted in spatial efficiency (e.g., circulation areas becoming places for workers’ informal meetings and exchange of ideas) and the reduction of energy consumption due to the effective use of artificial light with electric light control devices and lower level of embodied energy through the reduction of a quantity of used building materials.

Space planning with the location of individual workstations at the proximity of side windows is the most important formal measure taken into consideration. Implementation of effective technical devices assuring the maximum penetration of natural light, along with the control of gained thermal energy generated by the glazed building envelopes, is another more elaborated design method. Technical equipment, incorporated into inner spaces, makes it possible for office interiors to bring about the optimum ambient light and task light at workstations located in perimeters of office spaces. These solutions, based on structural and formal integration of technically developed equipment with building components, allow higher flexibility in the office layout due to the correction of space parameters (e.g., dimensions, proportions and to some extent also orientation) and in consequence result in more effective occupation of available workplaces.

2.1. Space planning and daylighting

In the Environmental Defence Office, conceived by EnvisionDesign (Fig. 1), completed in 2002 in Washington, USA, and certified with LEED-CI Silver level, the modification of parameters of existing skeleton structure of the refurbished high-rise, narrow proportions of the office building, have led to the introduction of reinvented combi-office spatial disposition, which was originally incorporated in Scandinavian buildings in the 70-ties of XX-th century. The main feature of space creation remains an idea of inner double row layout of individual interior
private offices, open workstations and perimeter offices, all located along the exterior glazed envelope. This formal concept, along with intensive use of transparent floor-to-ceiling or lower glass walls separating cells from each other and from the glazed envelope, enabled equal exposure of workstations to daylighting and workers’ nonobstructive visual contact with natural surroundings [4]. The restrictive rating system’s criteria regarding exigencies of daylighting standards, supporting building code regulations, stimulated this spatial configuration.

In the Amsterdam Office Tower, 21-storey office building conceived by UNStudio and completed in 2010, the layout of a typical open space office of 40m depth with centrally situated circulation core and fully glazed envelope, was complemented with four glazed atriums as recessed vertical voids which provide individual workstations located in a distance from external walls with equal daylighting [5]. The internal gardens are situated close to the atriums, which play a role of light shafts. Their glazing is supplemented with sun shades in the form of powder-coated aluminium lamellas differing in heights, widths and depths. A similar system is applied to the glazed building envelope. Reflecting thermal glazing, along with external sun shades, controls direct sunlight penetration and reduces inconvenient solar heat gains, thus protecting the indoor from possible overheating and reducing the costs of operation of the cooling system. On the lower floors these strips were replaced by horizontal fins deflecting the daylight into the offices. They play in fact a role of interior light shelves transmitting the daylight and protecting users from glare. Although the project has not been evaluated under any rating system, the office concept reflects designers’ approach towards sustainability achieved through the cohesion of architectural design.

### 2.2. Enclosures and daylighting

The strategy for reduction of the degree of shading workplaces caused by high partitions which divide them, as well as avoidance of physical buffers between working areas and building envelope disrupting views, encourages the implementation of transparent or translucent panels and screens ending well below ceilings. These space dividers should be situated preferably perpendicularly to glazed envelopes, thus permitting good daylighting and enabling effective space ventilation, as well as assuring necessary level of privacy for employees [6]. The suitable arrangement of workstations, furnishings, opaque fitting and screens should result in the formation of uniform daylighting and luminance on working desks. Accomplishment of these conditions can be assured by architects by way of research based on analysis of office layout, suitable arrangement of workstations, simulation of effective daylighting and accessibility to valuable view of exterior natural surroundings. In the case of certified Autodesk Office in Waltham, USA, conceived by arch.Kling Stubbins in

![Figure 1](http://www.archnewsnow/features/feature84.htm)
and certified with LEED-CI Platinum level, cohesive spatial, organizational and functional concept provided more than 90% of workers, as it’s recommended in the LEED rating system under which the project was evaluated, with visual contact with exterior environment from a seated position (Fig. 2).

Subjective partitions, made of light plastic semitransparent membranes fixed to floors and suspended ceilings, may be seen as another possible solution, as they allow transmission of daylight with the minimum physical intervention in the structure of existing office spaces. Pointwise fixing systems of light partitions allow their easy reorganization and encourage their future reassembly and modernization as well as diverse configurations. This solution, therefore, fulfills another sustainable design imperative concerning design for change, design for disassembly and space adaptability. The presented approach toward the inner space design allows for organizational, functional or technical alterations with significantly reduced amount of consumed materials and lesser refurbishment costs.

2.3. Passive-daylight devices
There are many technical devices which permit the concentration and redirection of incident visual solar radiation, as well as its transmission deep into the office rooms. They allow also to reduce inconvenient contrasts between well lit and shaded areas. Supplementary devices, named heliostats, in conjunction with optical systems, transfer effectively visual solar radiation to workplaces located far off the windows. Such systems can be implemented in existing buildings as autonomous internal structures, or as the elements integrated with external passive solar optic systems that control the supply of solar radiation. Application of technical building components gradually become commonplace in contemporary offices.

2.3.1. Light shelves and anidolic integrated ceiling (AIC)
One of the methods of effective control and distribution of daylight is the use of interior light shelves. The simplest and used for many years, most frequently applied systems of this kind, are the conventional internal light shelves, fixed or pivoted, made with horizontal elements and lined with stainless steel. As opposed to mirrored surfaces, they do not transmit the image of the sun due to the effect of light diffusion. This results, along with the use of partially reflecting, semi-transparent materials (e.g., acrylic panels, stretched fabric panels) allowing to avoid local disadvantageous shadows, in the uniform character of daylighting in inner spaces and in achieving high quality visual environment. Interior translucent light shelves incorporated into the open workspace of Boulder Ass. own offices located in a refurbished historical commercial building in Boulder, USA, completed in 2003 and certified in 2005 with LEED-CI Gold level, have been completed with highly reflective and bright finishing ceiling panels. This comprehensive system, supplemented with light monitors as an alternative of typical skylights, developed by architects, helped to manage the daylight at the building’s perimeter zone improving workers’ productivity and assuring their physical comfort [7], [8].
A similar effect of transmission and redirection of daylight has been achieved by the collection of solar radiation, and its further projection to interiors, assured by the so called non-imaging parabolic concentrators (Fig. 3). Alternatively, their modified versions are used with elliptic, concave, reflective surfaces redirecting the light up to the surface of the ceiling, which perform as reflectors. In practice, the implementation of this method consists in the installation of internal light shelves by windows or glazed envelopes in interiors approximately 3 meters high, about 2.1 m above the floor level [9].

These anidolic light shelves permit deeper penetration of solar radiation into the room comparing to conventional systems [10]. Both internal and external, fixed and adjustable light shelves not only enhance the daylighting intensity in inner spaces; they significantly reduce the inconvenient occurrence of glare blinding users of workstations located along exterior glazed walls, as well as moderate the excessive brightness, thus effectively improving working conditions.

Passive solar optic systems may increase the range of incoming visible solar radiation deep into the office room from regular 6m up to 8m [11] and thus enlarge the useful area of effectively lit workplaces.

Anidolic light duct integrated with suspended ceiling (Fig. 4) is another technical and formal method for improvement of daylighting conditions in offices. Non-imaging 50 cm high duct with highly reflective optical materials (e.g., post-anodized aluminium foil, silver-dot coating) is an effective solution that brings about high daylight illuminance at workplaces distant 3 to 4 m away from the glazed building envelope [9], [12]. The daylighting effectiveness of anidolic ceilings is hardly impaired by the insufficient direct solar radiation, or by the thorough overcasting of the sky. They receive the diffuse natural light from the upper parts of the sky that feature higher level of luminance.

**2.3.2. Passive solar optic systems (PSO) related elements**

The effective enhancement of daylighting by the use of passive solar optic systems in office buildings, can only be achieved when this issue has been considered and solved at a design stage. False decisions concerning the layout of the building, structure, and treatment of facades or space planning of interiors, can compromise the daylighting effect. The external collectors of direct or indirect solar radiation, sometimes coupled with prismatic filters of PMMA, introduced in order to eliminate the thermal component of the solar spectre, are usually located in front of the exterior glazing.
If they are adjustable, or equipped with heliostats, they are more effective due to the steady projection of “cool light” to inner reflectors integrated with PSO systems and mounted to ceilings. The daylight reflected from them is, then, diffused and improves the luminance at workplaces (Fig. 5). Reflectors are usually autonomous structures made with aluminium, stainless steel or plastic flat or curved panels. They may be formed by special sculptural treatment of the structure of a ceiling with reflective finishing surface as well.

The application of PSO system-related elements allows to reduce the area of zones with insufficient daylighting. With installation of additional reflectors, moreover, the areas of offices located by the windows are protected from excessive solar radiation and glare. This improves substantially the lighting comfort for the users working there. Some systems take advantage of heliostats, which are used to project the solar rays to optical systems located deep in the interior, that throw the direct light on working desks from above (Fig.6), [13].

2.3.3. Optic diffusors integrated with PSO

Passive solar optic systems may be supplemented with mobile internal diffusers, usually suspended from structural elements of glazed roofs. They are supposed to diffuse the incoming natural light within inner spaces.

An impressive example of application of such technical solution is the office and laboratory building of the biotechnology Genzyme Center in Cambridge, USA, conceived by Behnisch, Behnisch&Partner, completed in 2003 and certified in 2005 with LEED-NC (LEED for New Construction) Platinum level. Its comprehensive PSO system, installed over and inside the central atrium, is spectacular in many aspects. The atrium acts as a large return air duct enhancing ventilation system and a huge light shaft. The PSO system is composed of heliostats, tracking the sun across the sky, a battery of fixed mirrors, and supplemented with prismatic adjustable, according to changing daylight conditions during the day, perspex louvers attached to a steel structure of glazed roof.

Being complementary part of this system, nearly 800 prismatic mobiles made with PMMA panels, act as a secondary source of indirect natural light. Their performance is enhanced with reflective finish of some of the internal atrium walls, which are clad with stainless steel at the full height of this 12-storey, centrally located circulation core in the building (Fig.7). Opposite atrium walls, equipped with reflective vertical louvres, participate in distribution of light in the open inner space. The diffusers, along with reflective lighting walls, form a huge optical light tube that...
receives natural light from heliostats and collectors located above the glazed roof. They allow an effective diffusion of daylight inside the building down to its ground level [14], [15].

This composite system is a substantial improvement of daylighting conditions and reduction in the use of artificial light. The introduction of light shelves and passive solar optic systems into contemporary office buildings, therefore, turns out to be profitable, due to the optimization of firms’ operational costs. This results from the cutting down on expenditure for electrical energy used for artificial lighting during the daytime, as it requires 45% less electricity than for a conventional office building. Spatial disposition, supplemented with technical features, provides 75% of all workspaces with sufficient natural light for working without artificial lighting under normal conditions and offers to almost 100% of all regularly occupied spaces valuable views to the outdoors or indoor gardens [16]. An improvement in conditions of working in comfortable uniform and intensive daylighting contributes to better productivity related to higher psychosocial comfort for employees, and finally, to additional financial savings due to the reduction in absenteeism or staffing fluctuation. This carefully executed lighting system turned out to play an essential role in the spatial organization of interiors as well.

3. CONCLUSION

The sustainable interior design ensures high environmental quality as to the optimum most important parameters of indoor microclimate, like the quality of the inner air regulated through the use of building materials free of or emitting limited amount of volatile organic compounds (VOC), air humidity optimization through implementation of vegetation or reduction of noise. Adequate daylighting in workspaces is another essential element of this design strategy leading to the improvement of end users’ comfort. Social and environmental context of sustainable design of interiors should be considered and analyzed along with their economical aspect, which determines the acceptance or rejection of proposed functional and technical solutions. The interior design elements analized in the paper, may be seen as substantial in optimizing operating costs and reducing energy use through effective daylight distribution. Daylighting itself in this context may be considered as “sustainable lighting technique for the built environment that relies upon natural light for illumination” [17]. The carefully designed and executed daylighting systems realized through different formal methods and technologically as well as technically advanced solutions, may turn out to become an essential factor in the spatial organization of interiors, helping in creating their stylistic identity and structural integrity with building components as well. Comprehensive design regarding office interiors, through integrated, whole-building design practices as promoted and verified by LEED ID+C rating system, may improve daylighting conditions along with other indoor environment parameters, thus enabling the implementation of the paradigm of sustainable architectural design.
REFERENCES


