Analysis of Natural Lighting with Regard to Design of Sustainable Office Buildings in Poland

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Abstract. The study was a part of a larger research project which was devoted to simulation-based design analysis for daylit office spaces in Southern Poland. The paper consists of two main parts. The influence of various facade systems, lightshelves and fixed shading systems on daylight factor in the analysed office space is presented in the first part. These introductory analyses allowed to identify the optimal facade for an office building. The second part of the project included the comprehensive analysis of selected best performing architectural solutions. These analysis examined how lighting conditions were changing during typical time of an office work throughout the year. Illuminance levels and visual comfort were analysed. New issues like the performance of external retractable venetian blinds were added. This paper also investigates how state of the art simulation technology can be used to integrate natural lighting design strategies into the early stages of architectural design process.

Keywords: natural lighting design strategies, daylight analysis, sustainable office buildings, indoor environment quality.

1 Introduction

This project is devoted to simulation-based design analysis for daylit spaces. There were two main aims of the study and they are reflected in the structure of the project. So this paper consists of two main parts.

The first aim was to answer the question what facade system would be optimal for an office building in Southern Poland. Therefore the first part is devoted to the influence of various architectural solutions on daylight availability. The influence of various architectural solutions on luminous environment in the analysed office space was identified through computer simulations. This study examined the performance of various facades, lightshelves and fixed shading systems. The influence of various solutions on daylight factor was analysed, therefore the selected design solutions were examined only for overcast sky conditions and on December 21st, at midday.

The second part of the project included the comprehensive analysis of selected architectural solutions that were best performing in the first part of the study. These analysis examined how lighting conditions were changing during typical time of an office work throughout the year. The aim was to estimate how the changing position

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of sun would affect lighting conditions in the office – the daylight availability and visual comfort, and whether selected architectural solutions would meet the expectations throughout the whole working time.

In recent years many researches have proved that occupants react positively to daylight. Properly daylit offices can improve the overall well-being of their occupants. The healthy daylit indoor environments are linked to gains in productivity, increased occupant satisfaction and improved employee morale. The correlation has been well substantiated [5].

The Typical Sustainable, Energy-Efficient Office Building of the Twenty–First Century. During the whole twentieth century the common certainty was that technologically advanced systems, mainly ventilation, air-conditioning and electrical lighting systems, would cause an increase in efficiency, happiness and comfort of office workers. They were believed to solve all problems resulting from low light and air quality both inside and outside buildings [2]. Today air-conditioned office buildings with deep floor plates, containing large interior zones and large glazed surfaces are the most common type of building in centres of cities in developed world [17]. Still they are the symbol of high quality office space around the world. But outcomes of many researches confirm that the buildings do not meet the actual needs of their users [6], [8], [11], [18], [20]. At the beginning of the 21st century it became apparent that the sealed, air-conditioned, high-rise offices didn't realise hopes put on them. First of all they contradicted the concept of sustainable development.

So what kind of an office building should be analysed? A state–of–the–art intelligent office building should be environmentally friendly. This means that it is expected mainly to use less energy. A new model of sustainable development is based on reducing energy demand and on improving building performance and process [1]. The prevailing components of operating costs in an intelligent office building are the costs of mechanical ventilating, air-conditioning and artificial lighting [12]. The costs of air-conditioning of sealed, glass, high-rise office buildings with deep floor plates are particularly high. The annual HVAC energy consumption of a typical office building varies between 650 kWh/m^2 and 400 kWh/m^2 [10], [12], [17]. However the energy demand in the most modern offices has been reduced by 30 – 40% and even 70% reduction of energy demand has been achieved in state–of–the–art sustainable office buildings. Examples of these offices include Energon in Ulm (Germany) (81 kWh/m^2), and Manitoba Hydro Place (Canada) (100 kWh/m^2). The characteristics of the state–of–the–art, highly efficient offices are [13]:

- these buildings are as far as possible naturally ventilated and daylit,
- their facades are designed to prevent risk of overheating,
- they are typically designed with a narrow floorplate, so daylight can be effectively distributed,
- the buildings are also extended along the east-west axis, because it is much easier to manage heat gain and daylighting on north and south exposures. The east and west exposures are usually reduced. Quite often sustainable office buildings are organised as a series of a few south-facing office wings.

The office building designed for the analysis was about 77 m long and 15m wide. The building had a total area of about 4 600m^2. It had 4 storeys and was about 19 m high. The study focussed on the open-plan space. The analysed floor area was situated on the second floor and it was 10.8m in width and 9.0m in depth. It gave an area of 97.2m^2. The width of an office module was 2.7 m, therefore the space was 4 cellular office modules wide and 3 office desks plus corridor deep. A view from the top shows the analysed office room, see Figure 1. The building was assumed to have a floor-to-floor height of 4.2 m. The office space was 3.0m high, above the level there was a suspended ceiling and a concrete slab. The analysed office space faced south.

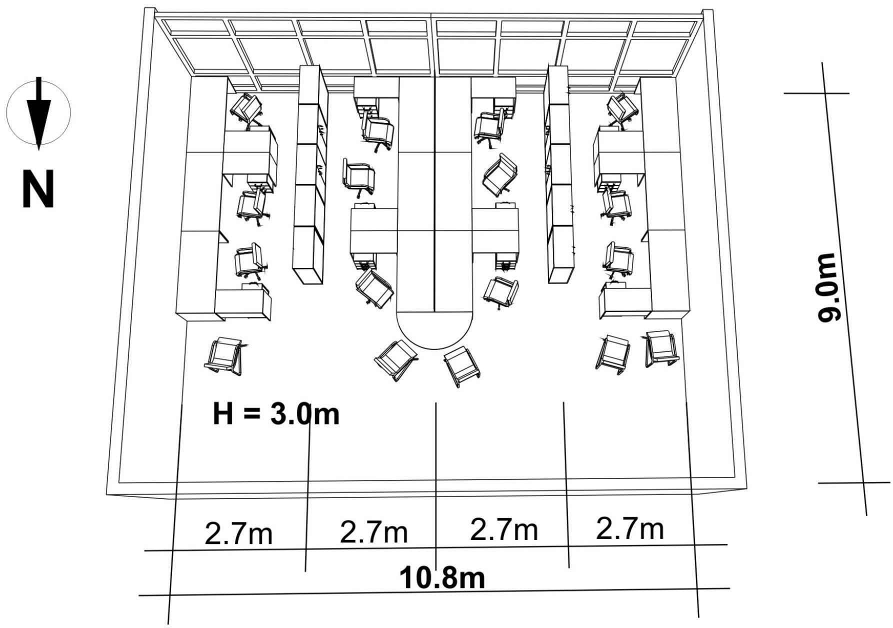

Fig. 1. A view from the top showing the analysed office room

2 Part I - The Analysis of the Influence of Various Architectural Solutions on Daylight Availability

The daylighting problem can be divided in three issues: daylight availability, visual comfort and energy use [14], [16]. During the first part of the study the daylight availability was analysed. The room was only illuminated with daylight, no electric lighting was included. When we use traditional side windows we experience the problem of uneven distribution of natural light. The illuminance is highest close to the facade, and then decreases quickly as one move further into the room [3], [4]. Therefore, sidelighting systems were proposed to reduce excessive daylight levels near the windows and increase them in the area of the room away from the facade. The aim was to achieve a more balanced daylight distribution throughout the room. Three devices were proposed, see Figure 2:

- the classic lightshelf (A) – it consisted of 90cm deep external sunshade and 60cm internal shelf,
- the advanced lightshelf 60 (B) – the collecting external part was 90cm deep and the internal reflecting part's depth was 60cm,
- and the last device was the advanced lightshelf 120 (C) – the internal part was deeper, 120cm.

The daylight factor was calculated for these three cases through computer simulations, the lighting simulation software used was Radiance and for the purpose of daylight factor calculations overcast conditions were simulated. Radiance has been called "the most reliable software available for accurate daylight prediction" [4], [19], it can precisely simulate the luminance and illuminance levels [7].

This study was performed with the main assumption that the materials of walls, ceiling, floor and furniture were the same. The room and furniture surfaces' reflectance was 70%. The Autodesk Ecotect software was used to adjust the properties of surfaces and materials, set up time, date, lighting conditions, orientation and to access the Radiance program. The virtual 3D building was modelled in 3D Studio MAX. The geometry of the created building was simplified as much as possible. The main aim was to decrease the computation time, but of course a sufficient level of accuracy had to be maintained. So the office space was sparsely furnished, only the most important visual elements that would interact with the daylight were modelled. Primarily office desks were added.

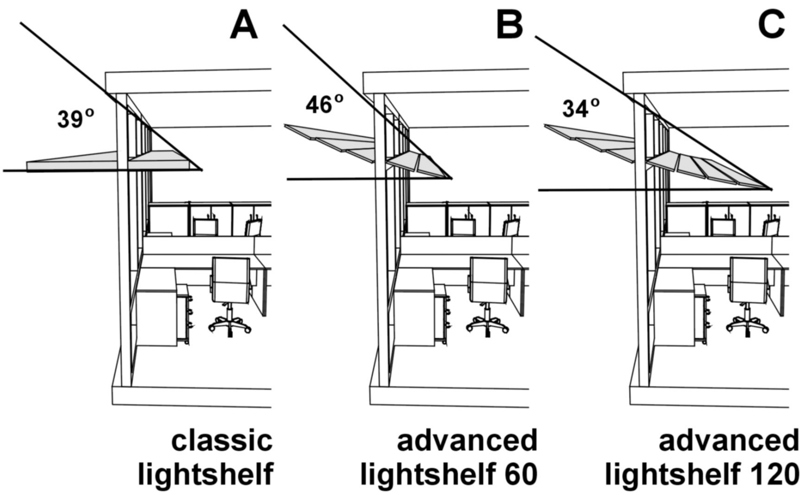

Fig. 2. Three devices were proposed to achieve a more balanced daylight distribution throughout the room

To calculate daylighting metrics an analysis grid was defined in Autodesk Ecotect. The "virtual sensors" were located on a plane 80cm above the floor. That was approximately at a height of a standard office desk. Radiance calculated DF values for these sensor points.

It should be highlighted that in fact lightshelf almost always reduces the amount of light received in the interior relative to a conventional, non-shaded window, but it also gives a more balanced daylight distribution throughout the room. The lowest light levels are for the case with classic lightshelf (A), but it also has the best ratio of DF near the windows to DF at depth of 8.5m which is 5.8. For the case with advanced lightshelf 120 (C) it is 7.1 and another advanced lightshelf – 6.6 (B). For the facade without any lightshelf the ratio is 8.

Bearing in mind that the aim for many designers of sustainable offices today is to achieve a minimum DF of 2% near every workplace, this can be said that the best solution is advanced daylight 60. In the part I of this study it was also analysed how the glass area of the facade would influence daylight penetration. Two different facades were compared, one with full height glazing and second where the windows constituted 73 percent of the facade area. The sill was at height of 80cm. The visual transmittance of the double glazing was 64%.

The ideal of an all-glass building has been pursued by architects for the past 100 years. And this approach, I purposefully do not name it a strategy, has not been effective. While we compare the highly glazed office space to the more moderately glazed one we see that the difference in the level of Daylight Factor is not considerable. However, in central Europe it must be remembered that against potential positive impacts including higher DF the negative impacts of heat gain and loss need to be considered. The increased glass areas lead to many problems. For example, due to lower thermal insulation of glazed facades poor thermal comfort is common in the winter time. We can also expect higher winter and night time heating requirements, and higher risk of overheating and increased cooling loads, when the intensity of the solar radiation becomes higher in the spring and summer [4]. It is much more economical to use transparency strategically. Therefore, for the further studies the 73% case was selected.

3 Part II - The Comprehensive Analysis of Lighting Conditions Throughout the Year for Selected Architectural Solutions Used in an Example Office Building

In the part II of the analysis a hypothetical building situated in Cracow in the southern part of Poland was examined (longitude: 20° E, latitude: 50° N). The footprint of the analysed building was designed along the east-west axis, but it was slightly rotated towards East. The angle of rotation was 19 degree. To properly design shading devices the effective solar heights have to be taken into account, therefore both the solar height and the azimuth angle must be known. While a building faces south at equinox the effective solar height is equal all working day (between 8 a.m. and 4 p.m.). For this latitude it is 40 degrees. Such building is the easiest case to shade. But the analysed building was rotated towards East. The effect of turning the office brought about difficulties with lower solar heights. At 8 o'clock the effective solar height was only 27 degrees, at 10 o'clock 35 degrees, and for example at 4 hour p.m. it was 76 degrees (these hours represent true solar time).

Sunny conditions were studied for two days of the year: 21st of June (summer extreme regarding solar heights) and 21st of March (the midpoint of the year). During the study the influence of various shading systems on daylight availability was simulated. While the shading devices were being designed, the aim was to protect office space through working hours. In all cases, the basic assumption was that the office was occupied between 8 a.m. and 4 p.m.

The effect of shading devices on solar transmittance must be well known at the design stage, because the knowledge is crucial if we want to properly protect building from excessive heat gains during summer and properly design the energy-efficient HVAC system.

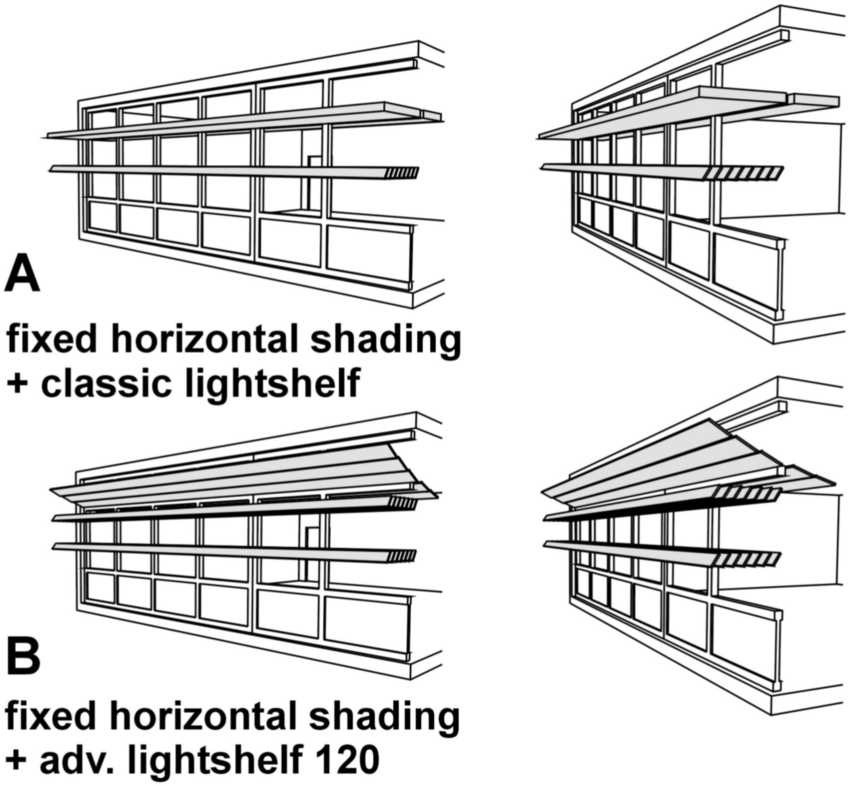

Fig. 3. Two selected shading devices were designed to protect south facade from the 21st march to the 21st September

The two selected best solutions were, see Figure 3:

- A: the classic lightshelf (60cm internal shelf, 100cm deep external sunshade) and the fixed horizontal shading,
- B: the advanced lightshelf 120 and two surfaces of fixed horizontal shading.

The selected shading devices were designed to protect south facade from the 21st March to the 21st September.

At the stage of the analysis of natural lighting two questions were asked:

- How do these various solutions affect the daylight availability in analysed office open-plan space?
- Does the advanced lightshelf really perform better than the classic one under sunny conditions?

Horizontal shading with classic lightshelf performs better than the advanced light-shelf with louvers. But the most important result is that both shades take away a considerable amount of the important diffuse light from the sky when compared to the facade with only the advanced lightshelf 120.

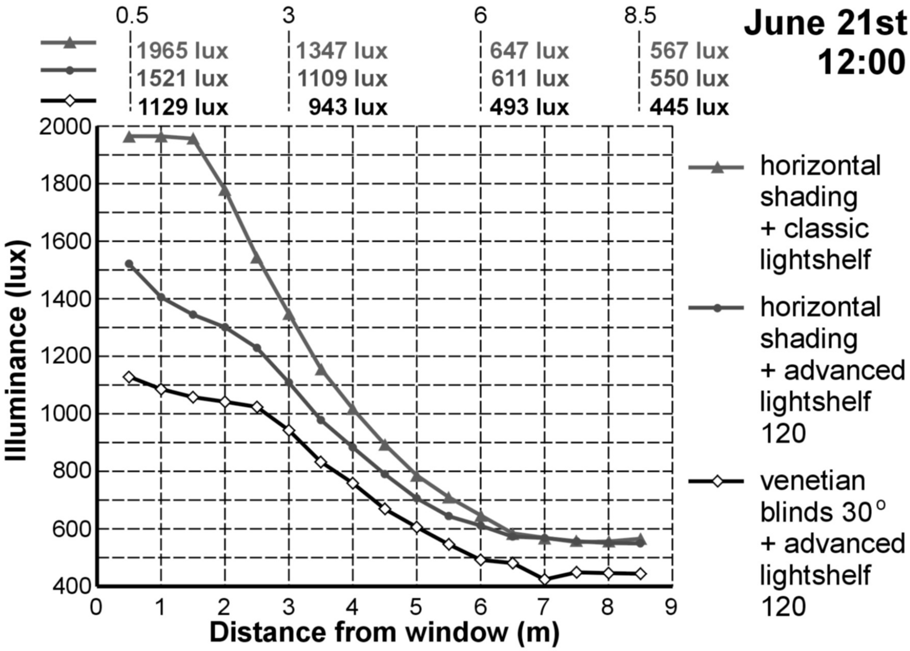

Fig. 4. Illuminance at summer solstice for three selected alternative designs (June 21st at 12.00)

Illuminance levels analyses and visual comfort analyses were done for three days: summer and winter solstice and equinox (see Figure 4). Three selected alternative designs were thoroughly investigated - two previously presented cases with external fixed horizontal louvers and one new. The new one was a facade with external retractable venetian blinds and advanced lightshelf 120. The angle of venetian blinds was 30 degrees. The idea of adding a new case was to verify how venetian blinds would influence the illuminance levels if external fixed shading devices were taking off so much daylight. The illuminance levels for venetian blinds case are apparently lower. But we have to take into consideration also the risk of glare. The results of visual comfort analyses showed that the luminance on the window plane in the case A exceeded the recommended maximum value of 2000 cd/m2, whereas the venetian blinds reduced it to about 1000 cd/m2. In the case A the risk of glare occurred, while the case with venetian blinds represented the acceptable level of luminance [4], [15]. To achieve a glare free environment in the case A for example interior curtains or blinds could be added, but the illuminance levels would go down significantly as a consequence.

4 Conclusions

It should be emphasised that we still do not exactly know when people feel comfortable in a lit environment. We do not know how to evaluate visual comfort [4]. Therefore the study was limited to an estimation of physical, quantitative measures like daylight factor, illuminance and luminance.

The conclusions are:

Lightshelves. The use of lightshelves provides a more balanced daylight distribution throughout the room. The classic lightshelf performs really good on south facade while for the north side the use of specially designed, advanced lightshelf should be taken into consideration.

Exterior Automated Retractable Venetian Blinds. The most promising strategy for energy efficiency and visual comfort in Polish offices appears to be the use of exterior automated retractable venetian blinds. They provide a very flexible solution, because they respond to variations of solar heights, can be adjusted to provide the window luminance preferred by user, and can be retracted to let maximum daylight into office space under overcast conditions. But it must be remembered that the decisive factors are occupant behaviour, and what automated systems can do. The common story is that a building has large windows but the venetian blinds are permanently closed. Occupants don’t retract them. Therefore if there is the risk that automated systems can be inefficient the best solution will be to design fixed external shading. The protection against solar gains will be guaranteed and daylight factor values will be still relatively high.

Glazed Facades. The best solution is glazing from table height up to a suspended ceiling. 100% glazed office does not provide significantly more daylight at the height of office desk than the suggested case.

Fixed shading Systems. If the office faces south, higher solar heights are experienced so fixed shading systems perform best of all. Moreover the lighting conditions inside a narrow-plan office building are equally good on south and north side.

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