The Impact of Solar Radiation on the Quality of Buildings: Research Methods

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Abstract. Daylight analyses presented in this paper are fragments of a wider research project. The daylight simulation study focused on the influence of various facade solutions on lighting environment in office buildings located in the south of Poland. The development of scientific principles lying behind correctly daylit workspaces in offices was the main project's aim. The another, equally crucial purpose was the development of design guidelines for office buildings in the southern Poland. Selected architectural solutions were compared in this study. They included facade solutions (window placements and shapes, glazing-to-wall (GWR) ratios), solar radiation reflectors (light shelves) and deflectors (venetian blinds). Moreover two types of daylight performance metrics were explored, static and dynamic. The objective of this document is to promote the use of the most advanced and sophisticated computer simulation methods, techniques and tools for sustainable building design regarding quality of daylit indoor environment.

Keywords: Daylight analysis · Indoor environment quality · Natural lighting design strategies · Sustainable office buildings

1 Introduction

A recent study showed that most architects don't understand energy use, even though they acknowledge its importance. Architects in all types and sizes of practice can and should be leaders in energy modeling, taking responsibility as designers for assuring that buildings perform to high standards. To do so, we must learn new terms, strategies, and methods of calculation, as well as how to integrate this knowledge into the early decision making of a project. Design of modern buildings should be carried out using the knowledge about conditions at a particular location, taking into account the environmental and urban space conditions. Using knowledge about conditions at a particular location and Climate Base analysis, we can plan and test different variants of solar geometry and architectural solutions for building models in order to select the optimal strategy of passive. The purpose of the passive design is the search for solutions that will reduce pEUI = predicted Energy Use Intensity the facility demand for energy.

The passive design is based upon climate considerations, attempts to control comfort (heating and cooling) without consuming fuels. Easiest way to control heat gain and heat loss and air flow is to use proper orientation and shape of the building. This actions helps

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also to maximize the use of free solar energy for heating and lighting and apply a free natural ventilation for building cooling. This can be achieved by finding such a building solid geometry to reduce its overheating. Therefore, in the study of the location of the object is needed to simulate the effect of body shaping to reduce energy gains. Reducing susceptibility to overheating of the object, we must bear in mind the special role in the preservation of natural light comfort. Architects must relearn how to use shade (natural or architectural) to control heat gain. Modern building facades are like balloons, very thin, and very important to the overall energy efficiency of the structure. They are also an expression of architect skills and create the building image-quality [17]. Office buildings and other objects studied in Poland as a university [18] or laboratory facilities [19] are particularly sensitive to the formation of the facade. This is due to the particular climatic conditions. Proper technical solution of the building envelope with planned routes depths less than 5 m, create a user-friendly environment. The authors decided to investigate the effect of solar radiation on the conditions in office buildings with a detailed analysis of the quality of daylight available for selected weather conditions, geolocation, and other technical - forming elements of the facade.

2 Researches - Introduction

Daylight analyses presented in this paper are fragments of a wider research project [11]. The daylight simulation study focused on the influence of various facade solutions on lighting environment in office buildings located in the south of Poland. The development of scientific principles lying behind correctly daylit workspaces in offices was the main project's aim. The another, equally crucial purpose was the development of design guidelines for office buildings in the southern Poland. Selected architectural solutions were compared in this study. They included facade solutions (window placements and shapes, glazing-to-wall (GWR) ratios), solar radiation reflectors (light shelves) and deflectors (venetian blinds). Moreover two types of daylight performance metrics were explored, static and dynamic. The objective of this document is to promote the use of the most advanced and sophisticated computer simulation methods, techniques and tools for sustainable building design regarding quality of daylit indoor environment.

3 Researches - Theoretical Background

The thesis that daylight and a view of the outside are appreciated by buildings' users have been proved by numerous researches in recent years. The effects of properly daylit indoor spaces are linked to advantages for occupants' productivity, learning, health and wellbeing [3, 5, 7–9]. A relatively new area of study is non-visual, physiological effects of daylight on human biological processes [1]. Daylight controls many biochemical processes in the human body, for example it synchronises the circadian clock and regulates discretion of hormones. More and more researches are showing that indoor lighting standards are inadequate for biological stimulation. Numerous studies have recently been devoted to an estimation of physical, quantitative measures: light distribution, daylight factors, illuminance and luminance [2, 4, 6, 8, 10, 11, 14, 15].

This study was based on three main conclusions. They were:

1. daylight is desirable by office's occupants and has an enormous influence on users' comfort, health and well-being,
2. the most promising strategy for energy efficiency and visual comfort in Polish offices appears to be the use of exterior automated retractable venetian blinds [10, 11],
3. 100 % glazed offices do not provide significantly more daylight at the height of office desk than offices glazed from table height up to a suspended ceiling [2, 10, 11].

4 Researches - Methods

This paper presents results of daylight computer simulations done for 4 different facades of an office building, various window placements, shapes, and glazing-to-wall (GWR) ratios were analysed. Various ways to distribute and redirect daylight (light shelves) and shading devices (venetian blinds) were also compared. The simulations were made with the assistance of the Autodesk Ecotect, Radiance, Daysim and Evalglare software. The reference office represented a south-facing sidelit open-plan office located in Cracow in the southern part of Poland (latitude: 50°N, longitude: 20°E). The footprint of the analysed building was designed along the east-west axis. The building was not obstructed by any objects in the neighbourhood. The analysed floor area was intended to give daylighting conditions typical of an open-plan space in a naturally ventilated and daylit office building with a narrow floor plate. The office room was situated on the second floor of a four-story office building. Its dimensions were: 10.8 m in width, 9.0 m in depth (office area of 97.2 m^2), a suspended ceiling was placed at a level of 3.0 m. The four facades' glass area-to-wall area ratios were as follows, see Fig. 1: O1 – 25 % (8 m^2/32.4 m^2); O2 – 60 % (19.5 m^2/32.4 m^2); O4 – 27 % (8.6 m^2/32. 4 m^2); O5C – 33 %

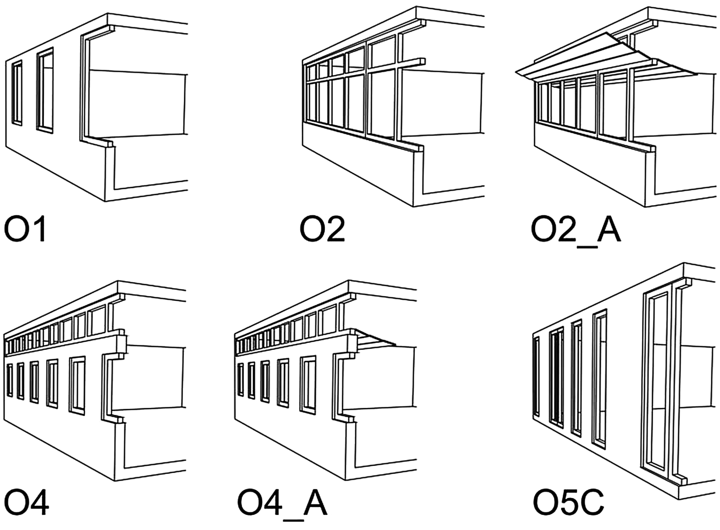

Fig. 1. Analysed facades

(10.6 m^2/32.4 m^2). The visual transmittance of the double glazing was 64 %. The reflectances of room surfaces were: ceiling – 85 %, floor – 35 %, walls – 65 %, light-shelf – 70 %, blinds – 63 % and furniture – 50 %. An analysis grid of "virtual sensors" was located on a plane 80 cm above the floor. That was approximately at a height of a standard office desk. During the computer simulations conventional, static daylight performance metrics as well as dynamic performance metrics were applied.

4.1 Static Daylight Performance Metrics

Static daylight performance metrics include daylight factor, view to the outside, and avoidance of direct sunlight. The static daylight studies consisted of three parts. Daylight Factor levels analyses, illuminance levels analyses and visual comfort analyses were done successively. Daylight factor is the superior static quantitative performance metric, it is the most widely used one, and it remains the only widely accepted one [13]. It is defined as the ratio of the internal illuminance at a point in a building to the external horizontal illuminance. DF is calculated under a CIE overcast sky. DF of 2 % on the work plane is at the present time recommended as an adequate daylighting level for office work. The first part of the static studies was devoted to the influence of various facade solutions on daylight availability (DF levels). The differences in lighting conditions are displayed in Fig. 2. The main limitations of the DF metric results from the fact that it does not consider season, time of day, direct solar ingress, variable sky conditions, building orientation, and building location [13]. The consequences are that DF analyses cannot help to develop shading strategies and glare prevention strategies. The aim of the two successive parts of the static studies (illuminance levels analyses and visual comfort analyses) was to balance

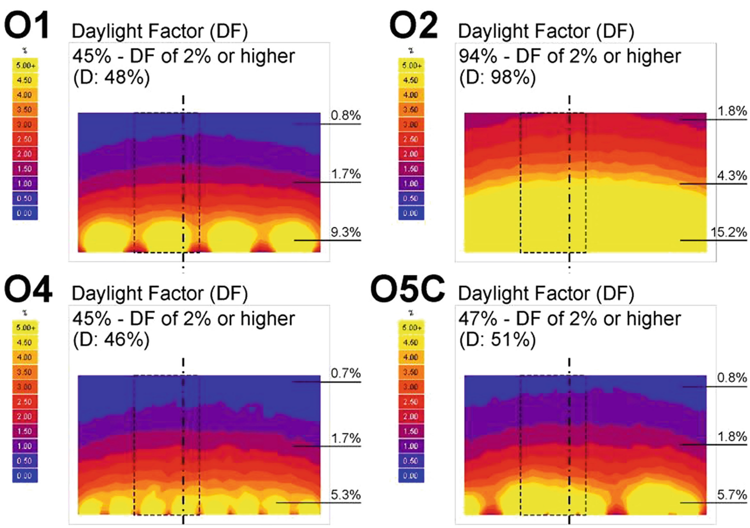

Fig. 2. Calculated daylight factor

DF metric limitations. Authors used a method of static daylight analyses, combining three types of analyses.

1. Daylight Factor levels analyses: they enabled preliminary assessment of architectural solutions. The worst cases were rejected. Selected solutions that had been best performing were analysed comprehensively.
2. Comprehensive analysis of lighting conditions throughout the year: illuminance levels (lx) analyses were done for two days of the year: 21st of June (summer extreme regarding solar heights) and 21st of March (the midpoint of the year). Sunny conditions were studied. The crucial aim of this part of the study was to evaluate the influence of various shading systems (external retractable venetian blinds 30° and redirecting blinds 5° + 30°) and lightshelves. Significant limitation of the analyses was that only the performance of fixed shading devices could be simulated. In practice Authors considered firstly various blinds' slat angles (0°, 15°, 30°, 45°) to find a glare free environment (see next point), secondly illuminance levels analyses were done for optimal lighting environment. The other goal was to ensure that direct sunlight was avoided.
3. Visual comfort analyses - luminance levels analyses (cd/m^2). It was assumed that if a value of luminance had not exceed the recommended maximum value of 2000 cd/m^2, a glare free environment would have been achieved.

4.2 Dynamic Performance Metrics

An alternative to the static daylight performance metrics are dynamic ones. They are founded on a precise computational method called 'climate-based daylight modelling' (CBDM). The concept of dynamic performance metrics is relatively new, an incomparable level of activity in the field of daylighting research has been observed in recent years. Until now a few metrics founded on CBDM have been formulated, the most popular are Daylight Autonomy (DA) and Useful Daylight Illuminance (UDI). US Illuminating Engineering Society published 'Approved Method: IES Spatial Daylight Autonomy (sDA) and Annual Sunlight Exposure (ASE)' document (IES LM-83-12) in 2013. In November 2013 the new LEED v4 rating system was launched at the Greenbuild Conference in Philadelphia and the LEED Daylight credit changed entirely, new dynamic metrics (sDA and ASE) replaced daylight illuminance levels in a clear sky conditions on September 21 at 9 a.m. and 3 p.m.. At June 1, 2015 LEED v4 will become the exclusive LEED certification system. The future belongs to dynamic performance metrics and computer simulations. Reinhart has written: 'since one cannot realistically measure illuminance levels for a whole year in a space, daylight autonomy distributions have to be calculated using computer simulations' [x15]. The main advantages of dynamic daylight performance metrics compared to static ones are:

- they consider the actual climate with its weather variations in which the analysed building is placed (An annual weather file is imported while dynamically simulating daylight. The most popular file format for annual weather data is the EnergyPlus Weather (EPW) file format);

- some daylighting computer programmes enable simulating of the performance of dynamic shading devices;
- the new approach considers too occupant requirements of the building.

The daylighting tool that was used to carry out dynamic daylight simulation was Daysim. This is Radiance-based simulation program. A grid of upward facing illuminance sensors that extended throughout an area of 10.8 m (width) x 6.0 m (depth) was defined. The grid resolution was 0.325 m x 0.25 m. Sensors were placed at 0.8 m above the floor (work plane height). Some of these sensors were selected as sensors close to where the occupant who operated shadings was located (core work plane sensors). Four cases of user behaviour were analysed (Daysim uses the Lightswitch algorithm (user behaviour model) created by Christoph Reinhart):

- no shading: space without shading;
- active A: dynamic shading device, active user sitting near the window;
- active B: dynamic shading device, active user sitting at depth of 5.0 m;
- passive: passive user.

Different user behaviours and locations of an occupant that controls shading devices were simulated to evaluate extreme daylighting conditions in an open-plan office. Dynamic shading device (venetian blinds) were controlled manually. Annual illuminance profiles were calculated for two shading device settings (blinds up, blinds down - slat angle of 45°). The analysed office was occupied from 8.00 to 17.00, Monday to Friday, and the minimum illuminance level was 500 lx.

5 Researches - Results

The first part of the static daylight studies (DF analyses) showed that although the glass area of facade O5C was larger than of facades O1 and O4, the DF values were almost the same, see Fig. 2. The conclusion is that the best solution is a glazing from table height up to a suspended ceiling. The highest light levels are for the case O2 that represents the best facade for an office building. The most interesting are the results of sunny conditions analyses after sidelighting systems and shading devices were proposed. Proper design choices (example of facade O4_A) can improve lighting conditions significantly, what is seen in Fig. 3.

Dynamic daylighting studies identified also the facade O4_A as the best case (the optimal reference case O2 is not considered), see Fig. 4. Moreover, they showed the percentage of the year when required illuminance levels were achieved by daylight alone. Authors calculated all the most popular dynamic daylight performance metrics: Daylight Autonomy, Useful Daylight Illuminances, Continuous Daylight Autonomy. Useful daylight levels (UDI 100-2000 lx) and exceeded UDI (> 2000 lx) for the cases O1 and O4 are displayed in Figs. 5 and 6. Results for various cases of user behaviour are also interesting. The best design solution should guarantee a comfortable daylight environment regardless of user behaviour. Seen from this point of view, the case O4_A performs incomparably better than O1.

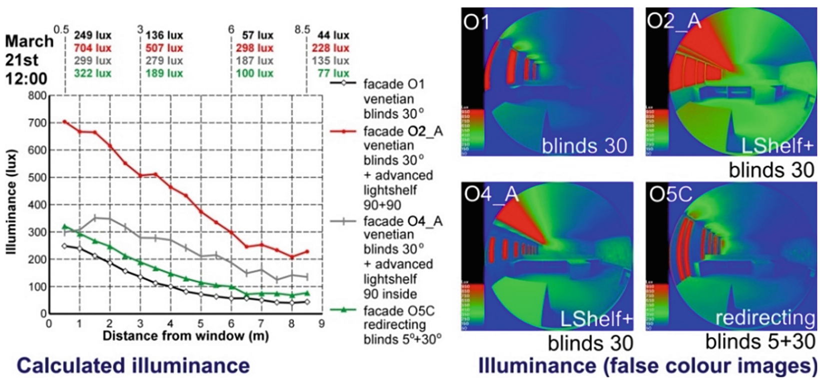

Fig. 3. Illuminance levels analyses - 21st of March (the midpoint of the year)

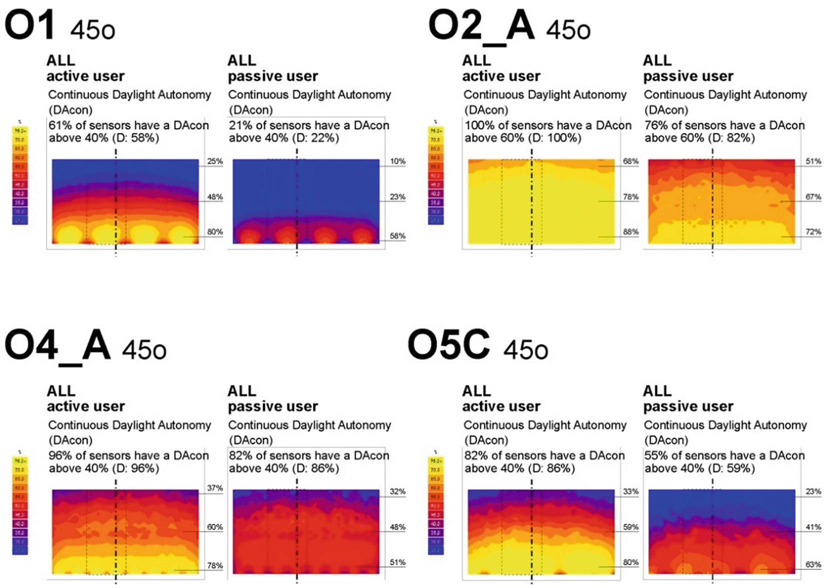

Fig. 4. Selected dynamic daylight performance metrics: Continuous Daylight Autonomy, Useful Daylight Illuminances 100–2000.

The O5C case represents one of the most fashionable facade solutions in recent years. The daylight analyses results confirm that fashionable facade solutions very often decrease the daylight levels and do not provide a balanced daylight distribution throughout the room.

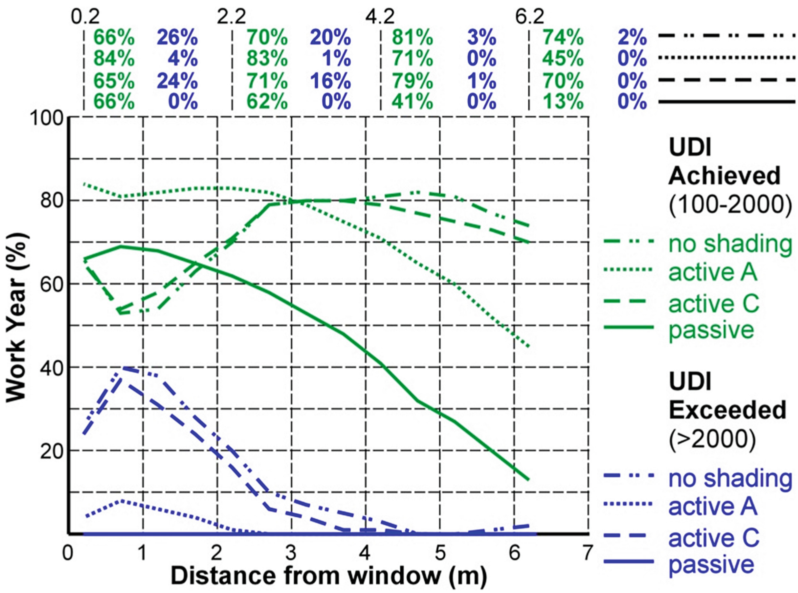

Fig. 5. O1: UDI – user behaviour

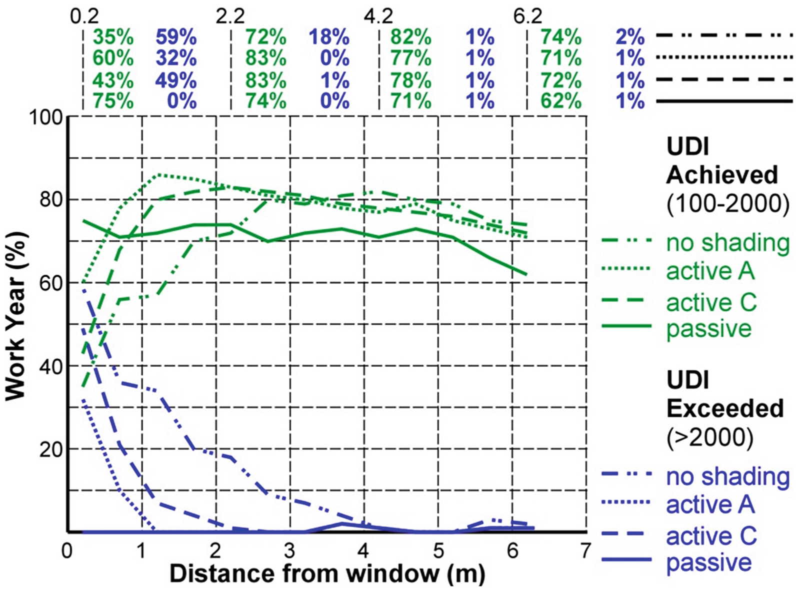

Fig. 6. O4: UDI – user behaviour

6 Conclusions

Dissemination of knowledge about methods to analyze architectural solutions in the context of assessing the quality of the built environment allows informed decision-making. Use of additional performance modeling tools, which assess thermal comfort, daylight penetration, glare-control, etc., alongside energy performance can lead to a space that is more productive, vibrant, and satisfying to the occupant. Maximizing daylighting improve health, stress levels, and productivity.

The conclusions are:

- evidence-based approach towards building design leads to higher-performance buildings;
- dynamic daylight analyses allow holistic evaluation of daylighting combined with solar shading and user behaviour;
- informed design decisions are the best way to improve significantly lighting conditions in office spaces.

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