IOP Conference Series: Earth and Environmental Science

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To cite this article: N Kutlar and M P Mengüç 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **290** 012145

Daylighting Design Process for Visual Comfort and Energy Efficiency for a Signature Building

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Abstract. Human comfort is the most important priority in designing living environments. Achieving thermal comfort, visual comfort, effective operation of a building along with innovative energy efficiency measures require extensive involvement of engineers and architectures in tandem for the future high-performance buildings. In this paper, we focus on design of the daylighting aspects of a complicated building and present a methodology. The concept here is based on the interactions of several stakeholders including the project owner, the project architect, structural engineers, façade engineers, mechanical engineers, lighting designers and electric engineers, who are involved in extensive discussions towards the design and construction of a complicated building in a ıniversity campus. Simulations are carried out using different architectural and computational techniques including DesignBuilder and Revit. The project constraints set by the stakeholder preferences are resolved with other engineering methodologies. This interactive process allowed a very favourable design of daylighting in the building. In this paper, the steps are discussed and the methodology is outlined.

1. Introduction

In recent years, the real estate and construction industry have shifted their attention to sustainable built environment as buildings and construction are responsible for more than the one-third of global energy use [1]. Several researchers have started exploring the interaction between users and visual and thermal comfort for designing and constructing the next generation high-performance living environments.

The globally widespread green building certification systems include visual comfort as a parameter for indoor environmental quality [2–3]. Yet, the percentage of green certificated building is very low. Therefore, it can be argued that number of buildings which pay attention to visual comfort is not significant. This means that the benefits of daylighting design is actually a lost opportunity for the rest of the building industry. In addition, the state-of-the-art daylighting design concepts based on systematic and scientific approaches are not used in even the best designs. Instead, either rule-of-thumb approaches' or none-architectural technics are employed despite the advances and accessibility of computational methodologies available for daylighting design. For these reasons, we wanted to detail our efforts to implement the best daylighting approach and practice for a signature building, based on our interactions with many stakeholders. This approach is expected to establish a repeatable methodology to have the most desirable natural light distribution to be achieved in a comfortable and energy efficient building.

In this context, the paper outlines how to balance visual comfort and energy efficiency in lighting design through introducing appropriate use of daylight for building occupants. First, different architectural technics are discussed to achieve the most desirable natural lighting scenarios. Following that, different computational technics are outlined showing how to achieve these goals. Detailed explanation about visual comfort and its impact on human physiology and psychology and on real estate sector, daylight metrics and daylight simulation software can be found in our paper that is in preparation.

2. Daylight Design Approach

Daylight design is discussed in various fundamental architecture texts [4–10], where steps to design daylight environment are given from various strategies from rules of thumbs perspectives to computer aided design methods. They also provide information about how to utilize daylight instead of artificial light and shares devices such as light shelves and light tubes. In addition, they discuss building elements from glazing properties to walls and ceiling materials. All of these sources helps an architect to design a daylight oriented building. Yet they do not provide directions and information for the role of architect for daylight design in an integrated project environment. To fill the gap in the literature, we work on developing a detailed methodology for daylight designers in the IPD (Integrated Project Delivery). In this paper, we present a systematic step-by-step approach, as shown in figure 1. First, the potential daylighting and visual comfort problems in a building are identified, and then they are presented to the entire project team. After that, the potential problems are tested using relevant simulation techniques. Finally, the most favourable decision should be amended according to the revisions from stakeholders. Following a brief overview of our practice and description for a signature building will be discussed and these steps will be outlined.

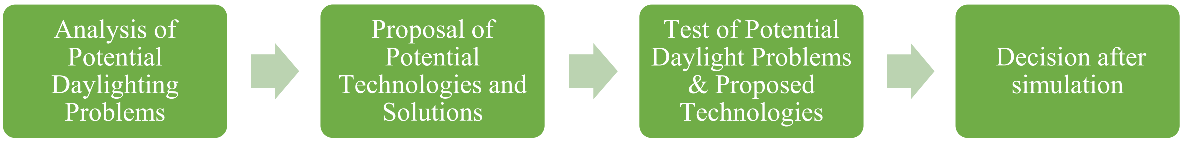


Figure 1. Workflow for the daylight design approach that is projected to form a methodology for IPD (Integrated Project Delivery) practice.

3. Daylighting Design of Case Study: AB4

In this section, our concentrated efforts towards the design of the daylighting of a signature building is discussed. In the process, we have aimed to ensure visual comfort and energy efficiency is achieved at the same time. In order to realize this, we have used different architectural and computational techniques together with suitable metrics.

3.1. Description of the Building

Ozyegin University campus, located in Çekmekoy, Istanbul, opened its doors in 2011. It is designed with notion of sustainable campus in mind as Green Metric criteria are applied, LEED green building certificates are issued and Low Energy Building methods commissioned by EU NEED4B project to CEEE is applied in one of the campus buildings [11]. Recently, the University has decided to build a new signature building, dubbed as the Academic Building 4 (AB4) which will house the College of Architecture and Design and the laboratories of the College of Engineering.

The AB4 building is comprised of three upper floors over the ground floor and six floors under the ground, with a total indoor area of 20531 m^2. The building includes studios, seminar rooms, exhibition hall, classes, offices, laboratories, a dean suite and a café. In this paper, we focus on offices and studios to make sure that lighting will be the most pleasant to all people working in the building. The main areas we are focused on this building are studios and offices in the building. The offices are at the east wing of the building. Below, we will explain the steps mentioned in daylight design approach with the AB4 case building.

3.2. Analysis of potential daylighting problems

The authors have been involved in this specific project after the preliminary design decisions have been taken and layout and drawings were completed. Therefore, energy and daylight optimization phase cannot be done. Using the drawings, potential non-lit and over-lit areas have been identified considering the completion of tasks according to spaces. Accordingly, it has been determined that offices at the east façade facing the adjacent AB1 building can be overshadowed causing low illumination levels as shown in figure 2. Secondly, as can be seen from figure 3, studio spaces are considered as particularly important since some of the desks were located next to West and South facades. These spaces can receive too much light causing visual discomfort. In addition, the light wells might cause either over-lit or non-lit problems if not perfectly designed as shown in figure 3. In addition, the studio spaces at Level 132 and Level 129 are fitted with skylights which suggests that their design should be scrutinized.

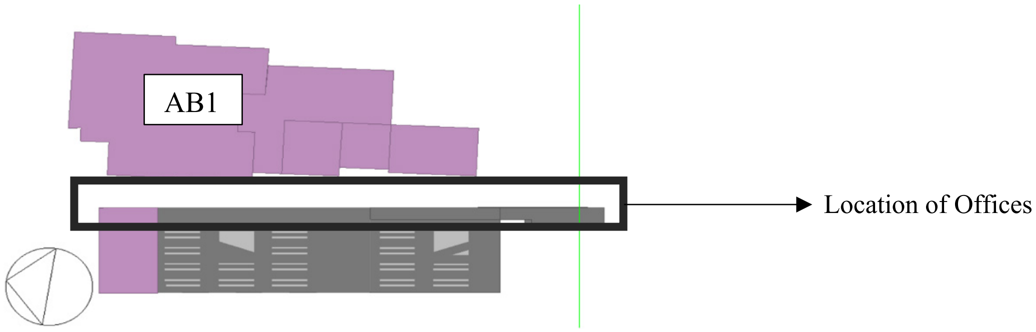


Figure 2. Layout plan of AB4 Building. AB1 casts shadow on AB4 offices suggesting that the employees might not receive adequate light for the completion of their tasks. Skylights are located on the roof allowing for natural light to be penetrated in studios at Level 132 and Level 129.

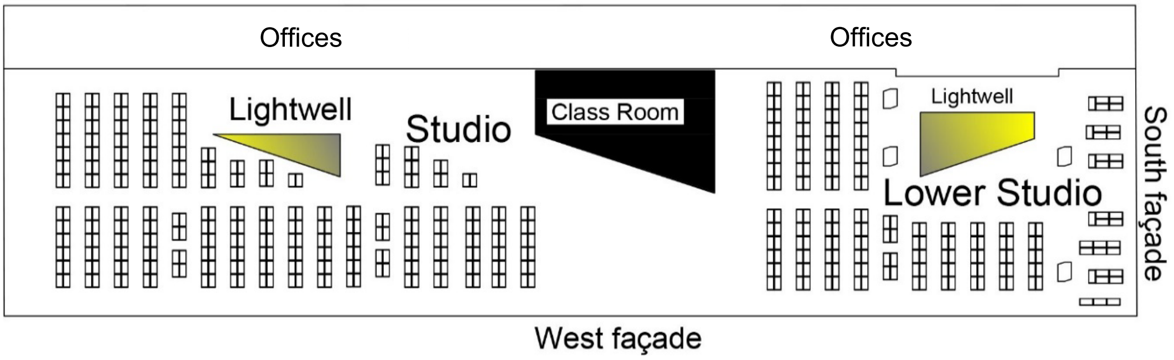


Figure 3. Light wells, west façade and south façade locations. West and south façades might cause over lit areas as some of the desks are located next to these façades and light wells should be designed for avoiding over-lit and non-lit circumstances.

3.3. Potential of daylight technologies and proposed solutions

After the potential problems has been determined, potential solutions have been provided to discuss with the team. This step is particularly important as it helps reducing the time spent for computer modelling and simulation by omitting some of the solutions that would not fit to project constraints. Anidolic ceiling systems, light shelves, skylight roof, solar tubes with daylight combined thermal solutions such as solar stacks, and ventilation facilitator solar chimneys are shown as potential applications. Photovoltaic Panel Integrated North Roof, Anidolic Ceiling, Light tubes and Light Shelves are further discussed with stakeholders and revealed two main suggestions as given below.

3.3.1. Enriching daylight solutions with other environmental benefits. While proposing solutions for visual comfort, it is suggested to enrich the solution with other environmental and energy efficiency benefits. For instance, for the studio space, a novel combined structure of photovoltaic panels and north light roof is proposed to provide both visual comfort and energy efficiency by installing photovoltaic panels on the south side of the north light roof. This option is found favourable as the southern and western solar radiation would also be blocked. However, the static team found this option too challenging to achieve considering the wide opening in the studio space which is 18 m. Our suggestion was to increase the static properties of elements such as use of higher concrete class to increase reinforcement. Nevertheless, the option is not implemented because of tight budget.

3.3.2. Selecting feasible options for analysis. Anidolic ceiling are found not applicable for the offices as they require additional floor to floor height in the rooms resulting in considerable increase in the façade area. However, lower floor height could be an option too. The height of the offices were 2.65 m and the distance between windows to door is 6m. Since an anidolic integrated ceiling might require 40−50 cm according to the studies [12] [13], we chose to keep the 2.25m–2.15 m net office height during this step. These height dimensions are too low for a comfortable space, therefore, light shelves are found more applicable for the offices.

3.4. Testing of potential daylight solutions & proposed technologies

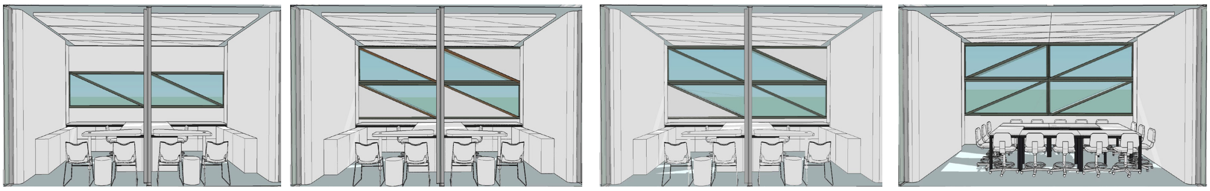
The green building industry in Turkey is mostly developed around Revit and DesignBuilder software. Therefore, both of these two software are used and Revit Insight is recommended to as a result of this study for the following reasons: Despite the fact that DesignBuilder provides very easy modelling experience in terms of building mass design and definition of material properties, Revit is capable of yielding faster results and not blocking the software and computer use while the simulations are running. The aspect of modelling duration in Revit can be minimized by using conceptual mass option and turn all the elements into building elements afterwards. It must be noted that if change in threshold for sDA is needed, DesignBuilder must be used as in the case of the studio calculations, since a sDA threshold is not changeable in Revit.

Since, satisfying energy efficiency and visual comfort together, Spatial Daylight Autonomy (sDA) and Annual Sunlight Exposure(ASE) metrics are selected as suggested by IESNA standard [14]. Here, sDA refers to energy efficiency and ASE refers to glare [14]. It is aimed that sDA value to achieve at least 55% while aiming to have low ASE percentage as suggested [14]. To be more accurate on ASE percentage value, LEED v4 daylight credit requirement is followed, targeting 20% or less [15].

3.4.1. Daylight analysis of east offices. This practice showed that daylight analysis should be done for the overall building, instead of picking representative areas as the results belonging to picked offices are misleading when the overall building is simulated. Initially, two offices at the level 135.00 which is the highest level of the building and named as Office 1 and Office 2 in the entire study are picked. A glazing type which has 50% Visual Light Transmission (VLT) value and 0.33 Solar Heat Gain Coefficient (SHGC) value is used in the simulation as selected by the façade engineer and architects. In the original design, the height of the window was 1 m. In addition to this size and form, we were asked by the architect to try different window styles as given in figure 4.

It is seen from the analysis that all options provide 100% sDA values, suggesting that all options may allow adequately lit environments as shown in the table 1. However, as for the ASE values, options provide relatively high percentages against the metric goal. The only acceptable result was by Office 2 of option 2 which is 17% of the total. Accordingly, the use of light shelves in Office 1 and Office 2 were suggested. All window configuration options are tried with 30 cm interior light shelves. Despite obtaining significant reduction in ASE for all cases, the recommended value mentioned by LEED v4 is not achieved. Solely Option 1 achieved LEED v4 requirements for both offices as providing 12% and 17% ASE values, respectively. Consequently, in order to reduce ASE values to achieve lower glare values, the use interior and exterior light shelf systems are proposed, which are comprise of 30 cm interior and 30 cm exterior element. The results show that ASE values for both offices are 0%, which suggests an optimum environment for visual comfort and energy efficiency. Consequently, using Option 1 and Option 2 with interior and exterior light shelves are recommended based on the simulation. Option 1 is selected by the project team for its simple installation properties.

On the other hand, when east offices (at all floors) are analysed together after the preliminary design is completed, it is seen that Option 1 did not provide adequate conditions for all offices. The result showed that 60% sDA values as given in table 2. It was also observed that the Level 117 and 120 would have under-lit offices. Consequently, the height for Option1 was increased to 1.5 m, re-named as Option 5 in table 2. This new option was tested separately, as the implementation of lightshelves is cancelled due to the budgetary and technical issues as declared by the owner. Consequently, sDA is increased as desired, however it caused the ASE values increased by 6%, resulting in potential glare.



Option 1 Option 2 Option 3 Option 4

Figure 4. Window configuration options considered for the daylight simulations. Option 1 is the original design with 1 m height and 2.8 m width. The widths and heights are equal for all options.

Table 1. Daylight analysis results for different window configurations. All options provided 100% sDA values, yet, ASE values are over 20%, except for the Office 2 Option 2. Consequently, additional simulations were carried out for interior light shelf option. Exterior light shelf option was also added to the design to obtain nearly zero ASE values, despite it causes significant variations in the results. Option 1 with interior and exterior light shelf yielded 0% ASE value, suggesting a visually comfortable environment.

		sDA	ASE	ASE values with interior light shelf	ASE Value with interior & exterior light shelf
Option 1	Office 1	100%	25%	12%	0%
	Office 2	100%	27%	17%	0%
Option 2	Office 1	100%	17%	12%	
	Office 2	100%	30%	27%	
Option 3	Office 1	100%	33%	17%	
	Office 2	100%	47%	33%	
Option 4	Office 1	100%	50%	38%	
	Office 2	100%	50%	37%	

Table 2. Overall result for the offices on east façades on all levels of the building. When Option 2 is used, sDA levels are higher suggesting that energy will be less consumed. However, ASE values are higher than the one for Option 1 suggesting higher possibility in glare will occur. All offices at all levels are analysed for final decision.

	sDA	ASE
Option 1	60%	23%
Option 5	76%	29%

3.4.2. Daylight Analysis of Design Studio. The overall daylight performance of studio spaces is affected by light wells, skylights and facades that surround the studios. Since the glazing of facades were chosen as 50/33 in the overall building no additional changes were suggested. Based on these simulations we recommended VLT values of approximately 70% for the light well glasses. Consequently, we prefer to give specific attention to the skylight option of studios. Simulations were carried out for different glazing options provided by the façade engineer. These options had VLT values of 50% and 60%, SHGC value of 0.24 and 0.29, respectively. These glasses are named as Glazing 1 and Glazing 2 in table 4.

IESNA committee currently favours a target illuminance 300 lux for offices, classrooms, library type spaces [14]. However, for studios, where particular activities which are CAD aided design and drawing take place, 300 lux might not be sufficient. The standards such as CIBSE and TS-EN 12464-1 show different lux requirements for studio space activities as given in table 3 [16] [17]. Accordingly, it has been agreed that a method that blends IESNA sDA/ASE methodology with CIBSE Guide and TS EN 12464-2 lux level recommendation should be used. Indeed, in addition to 300 lux threshold of sDA, 500 lux and 750 lux are set as thresholds to analyse the conditions for both drawing and CAD tasks. It is agreed that ASE percentage over 1000lux/250 will be the same for all cases as it chosen as the indicator of glare as the IESNA standard suggests and 50% of occupied hours are taken same for sDA calculations [14].Our simulations show that Glazing 1 and Glazing 2 provide the same results for ASE. ASE value of 0,6% suggests that glare would be very low as shown in table 4. For the sDA values of Glazing 1 and Glazing 2, simulations show no difference for 300 lux condition; however, there is 1% difference for the 500 lux scenario and about 4% difference for 750 lux scenario.

Table 3. Recommended lux levels according to the standards and lighting guides for studios [16] [17].

Standard or Guide	Task /Activity	Recommended Lux Value
TS EN 12464-1	Classrooms for drawing	750 lux
	Computer Rooms	300 lux
CIBSE Guide	CAD Design Areas	300–500 lux
	Drawing Office	500 lux
	Drawing Boards	750 lux

Table 4. sDA and ASE values according to different glazing types: Glazing 1 and Glazing 2 against lux thresholds are obtained from TS EN 12464-2 and CIBSE guides. Similar results are obtained for both glazing types.

	300 lux		500 lux		750 lux	
Glazing type	sDA	ASE	sDA	ASE	sDA	ASE
Glazing 1	99,9%	0,6%	97,8%	0,6%	87,8%	0,6%
Glazing 2	99,9%	0,6%	98%	0,6%	92%	0,6%

3.5. Design Decision based on Simulations

As observed from the extensive simulations carried out, the illumination levels at the east offices may not meet the thresholds required by either ASE and sDA metrics. Option 5 shows higher sDA value, allowing more daylight to penetrate in level 117 and level 120 offices and therefore minimizes the use of artificial lighting. On the other hand, it provides 6% more ASE value causing higher glare and visual discomfort as indicated in table 2. Based on these results, we preferred the options where the energy efficiency is maximized. This corresponds to the cases where the natural lighting is higher, rather than undesired glare conditions. We think that the negative effects of glare can be minimized by using blind curtains when excessive glare occurs during the specific times of days. As a result, the Option 5 is selected.

The analysis of studio spaces showed that different VLT values for glazing did not cause any significant difference in SDA and ASE values. The reason for this is due to the low differences between the Glazing 1 and Glazing 2 options for studios. We note that Glazing 1 has lower SHGC value which suggests that heat transfer will be lower, resulting in reduced energy consumption compared to Glazing 2. Hence, Glazing 1 is recommended to be used for skylight scenarios for the building.

4. Conclusions

In this paper, a daylight design approach is outlined for both visual comfort and energy efficiency through a case study for a signature building at a University campus. Those who work on the construction of buildings pay little attention to visual comfort. It is considered by only sustainable construction industry to receive green building certificates, yet such an analysis should be applied to all new buildings to achieve both the visual comfort and energy efficiency through the lifetime of any building.

Based on the daylight design approach introduced, following steps are recommended: First, the daylight designer should carry a detailed numerical simulation to determine the potential daylighting problems. Second, the potential technologies and solutions to be used should be listed. Third, different scenarios should be studied carefully to test different cases, and provide different solutions for different problems. Fourth, final decision should be made by architects, construction engineers, lighting engineers and mechanical engineers in tandem.

In addition, our study has revealed the importance of the following key points:

- Use of daylight metrics ASE and sDA by IESNA standard should be carried out as they allow achieving both visual comfort and energy saving together. Revit Insight software is to be used for daylight analysis when sDA and ASE are taken as metrics.
- In the analyses, the space function should be considered while using the metrics, and the amendments to the thresholds should be done as needed.
- Analysis of the entire building is recommended to achieve visual comfort and the energy efficiency to avoid mistakes. Partial analyses of different parts of the building are likely cause dramatically different results.
- We recommended a novel Photovoltaic Panel North Light idea for these types of signature buildings to achieve the best environmental and energy efficiency considerations. The appropriate glazing and thermal properties should be considered for studios.
- Interior and exterior light shelf system can be designed together to provide maximum sDA values (100%) and minimum ASE values (0%).

It is shown in this study that daylight technologies need to be implemented after carrying out careful, detailed and extensive simulations. These simulations will help to different problems of the design and construction phases, including tight budget restraints, technical constraints set by engineers, and the hesitations in applying these technologies to new buildings.

Acknowledgments

This work was supported by CEEE at Ozyegin University, Istanbul, Turkey.

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