A STUDY OF THE DAYLIGHT ANALYSIS AND SHADING DEVICE PROPOSAL FOR RETROFITTING A CLASSROOM

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Abstract- The classroom is most commonly considered space in educational facilities where daylight is often a primary consideration for user comfort.This research paper aimed to propose a visually comfortable environment forthe renovation of an educational building by considering daylight distribution in classrooms.The case study was carried out to evaluatethe effect of direct sunlight penetration through side and clerestory windowsof a selectedmulti-functionalclassroom in Uludag University Faculty of Architecture.Shading system was designed according to the Giovani bioclimatic chart and Olgyay's graphical method of shading mask.Within the scope of this paper, daylighting scenario for 21st March equinox, 13:30 p.m. is presented. Combination of different parameters for shading device design such as material, slat angle and position were modeled and testedby using a simulation tool.Daylight distribution for the base case and retrofit scenario for proposed shading device are explained and compared by the help of figures and tables in the results.

Index Terms- Daylight, classroom, shading device, lighting simulations, visual comfort

I. INTRODUCTION

Interior daylight illuminance as a primary and dynamic light source, depends on season, location, latitude, cloudiness and obstacles that surround a building. Apart from direct sunlight entering from the window, diffused daylight that a space is exposed depends on the size and position of the glazing, surface colors, the depth and shape of the room and reflected light from the outdoor and opposite surfaces. Therefore, it is necessary to take into account natural and physical parameters in building design for benefitting more from daylight. Besides the positive effect of natural light on human health andcircadian rhythm, daylighting in educational buildings has crucial impact on learning performance and alertness of students. To provide and maintain an efficientstudy environment, educational buildings should use daylight at maximum to increase the success of students and academic staff[1-3].

Integrated lighting design requires minimizing the artificial lighting operating time by profiting from daylight as much as possible. Together with an efficient artificial lightingand automation strategy, solar control in educational buildings is vital in visual comfort and energy savings. Natural light penetrates from window openings and it allow occupants to have a visual contact with outdoor. The ratio of the total area of windows to the overall façadeis commonly represented by the window-to-wall ratio (WWR). Along with WWR, proper selection of glazing and shading device providing glare control and redirection of light is important to meet integrated lightingdesign goalswhile decreasing cooling and artificial lighting loads[4].

In literature, there exists several research papersabout visual comfort, shading device design and energy efficient lightingin educational buildings. Tzempelikos and Athienitis, for example,evaluated shading device properties and glazing area's effect on cooling and lighting loads [5].Kesten [6],used Insel and Radiance simulation tools to evaluate the lighting performance of an existing school and proposed an energy efficient lighting system. Szepessy studied control-oriented occupant behavior toward shading and lighting systems in an educational office [7]. The author defined behavioral patterns, measured indoor conditions such as temperature, relative humidity, internal and external illuminance and convert them into user models for simulations.Holmes and Hacker evaluatedlighting performance of a school by using Energy2 [8].Similarly, Krüger and Dorigoinvestigated the daylighting performance in terms of illuminance and luminance in classrooms by using Radiance and Ecotect simulation tools [9].

Designing with daylight is an important issue in energy savings. Güvenkaya and Küçükdoğu analyzed energy efficient design principles of elementary schools by identifying envelope configurationsand calculating daylight levels byRadiance [10]. Ferreira, Soares and Rocha [11]evaluated the impacts of lighting control systems.They computed the daylight autonomy and the levels of illuminance by another simulation tool called Daysim.Bellia, Falco and Minichielloanalyzedthe energy savings related to use of shading devicesof an office building by evaluating the energy demand of lighting, heating and cooling systems [12]. Kazanasmaz and Fırat, modeled an architectural design studio in Ecotect and Radiance; simulations were conducted to analyze the classroom's daylighting performance. They applied a light shelf and a laser-cut panel in the model and compared the daylighting performance of the existing case with the proposed one [13]. Maestre et al. studied varioussolar shade overhang and side fin typologies together with buildings' façade orientations, locations and latitudes [14].

This study aims to control illuminationlevelsby means of direction and distribution of direct sunlight

anddiffused skylight in order to improve currentvisual comfort conditions fora typical, South-east oriented, 110m^{2}sized classroom in Faculty of Architecture, Bursa Uludag University. Design parameters such as location, orientation, latitude, cloudiness, outdoor obstacles, side-light and top-light systems and shading device configurations were studied as inputs. Among various retrofitting scenarios conducted for combinations of days, schedules, building solar orientations and CIE sky-models, this paper includes, but not limited to,daylight distributionevaluationand shading device proposal for a classroom façade.

II. CASE STUDY BUILDING

A. Description of the Case Building

U.Ü. Faculty of Architecture building is chosen to design shading device proposal. The building is located at 40°13'38.3 "N latitude 28° 52'37.6" E in Bursa province, Nilufercounty, Gorukle district. The aerial photograph of the faculty, the images taken from outside and courtyard of the building and selected classroom for daylight simulations are shown below in Image 1, 2 and 3 respectively.



Image 1. Bursa Uludag University Faculty of Architecture Building [15]



Image 2. Photographs Taken from Outside and Courtyard of the Faculty Building

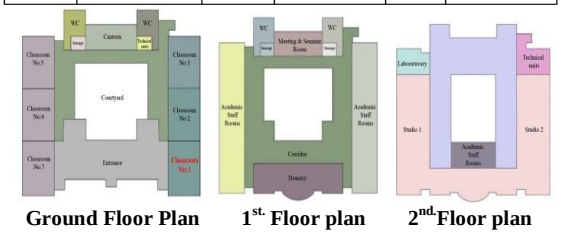


Image 3. Photographs Taken from Outside of SE Oriented Classroom Selected for Daylight Simulations

The three-storey building has a rectangular floor plan (42.8 x 51m). The total covered area is 3568 m² (ground floor: 1428 m², 1st floor: 1200 m²; 2nd floor: 940 m²) and the classrooms surround an open courtyard of 359 m². The total height of building is 11.15 m. The main entrance is oriented to the southwest-northeast direction. On the ground floor, the canteen and the rest rooms are located to the northwest; the classrooms on two sides of the courtyard are located to southwest and northwest direction. The academic staff rooms are located on the 1st floor in the southeast-northwest direction. Layout information and schematic plans of the building is given below in Table I and Fig. 1.

Table I. Space Distribution by Floors

Ground Floor		1st. Floor		2nd. Floor	
NE	WC	NE	WC	NE	Lab.
NW	3 x Classrooms	NW	Academic staff	NW	Studio 1
Court yard	Corridor	Court yard	Corridor	SE	Studio 1
NE	Canteen storage	NE	Meeting room	NE	Academic staff rooms
NE	Canteen	SW	Deanery		
NE	Technical units	SE	Academic staff		
SE	3 x Classrooms				



Ground Floor Plan **1st. Floor plan** **2nd. Floor plan**

Figure 1. Schematic Floor Plans of the Case Building

B. Room Specifications

The physical properties of the sample roomand the layout were obtained from the architectural drawings of the faculty building. By utilizing drawings and obtaining visual data by field observation, case study Classroom No 1 in Image 4 with insufficient daylight performance was selected for the daylight simulations.

The selected conventional space has a multipurpose use and has a free seating arrangement usually in rows for theoretical courses or in groups for the applied courses of architecture.



Image 4. Photograph taken from Inside of the Classroom

The room width is 12,5 m, room depth is 8,70 m and the height of the ceiling is 4 m. The main façade is oriented to South-East. The single volume space only receivesdaylight from SE direction and does not have any shading devices or cantilevers on the façade.Drawingdesksare 80 cm x 100 cm andtheseatsare 42 cm x 50 cm andbetweentwoseatsthereexistsrowlineabout 90 cm, as seenin Fig. 2.

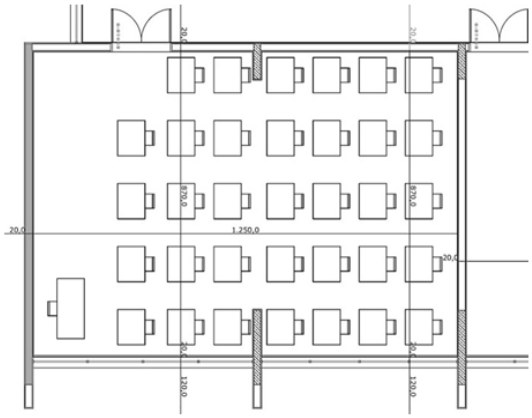


Figure 2. Layout of the Selected Classroom

The classroomhas side windows and inclined clerestory windows. Double glazed side windows with sliding opening sashes are located on a solid spandrel 90 cm high and they meet high inclined clerestory windows that reach to the ceiling above. Operable blinds are used to adjust sun penetration for daily and seasonal changes as needed. Façade configuration is given in Fig. 3.

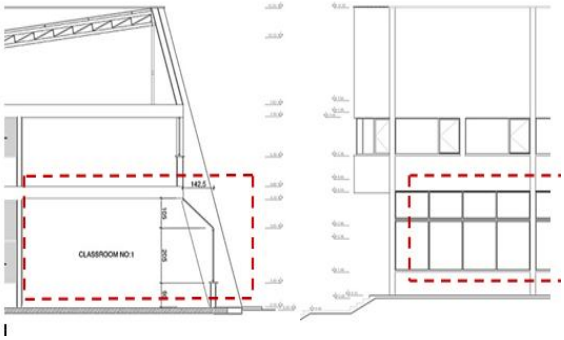


Figure 3. Window and Façade Configuration in the Section and South-East Façade Elevation

Light transmittance of the glazing and light reflectance of the internal surfaces of the classroom are given in Table II.Clear glass type allowshigh transmission of daylight together with solar heat to enter into the classroom.

Table II. Building Element Specifications of the Selected Classroom

	Walls	Floor	Ceiling	Glazing
Color	Light Blue	Gray	White	Clear double glazing
Reflectance	59%	22,3%	70%	10%
Transmittance	0%	0%	0%	70%

III. CALCULATIONS OF DAYLIGHT DISTRIBUTIONS

C. Daylight Distribution in the Existing Project

DIALuxEvo8 simulation tool is used to obtain illumination level in the classroom. A reference cloudless sky (The CIE clear sky model) is used for daylight analysis. The working plane is defined as 80 cm above the floor level. Daylight analyses is calculated for 13:30 on the 21st March equinox. As seen in Fig. 4, in front of the side windows daylight level has the highest values (~max 51.000 lx) and gradually reduces towards the inside of the space.

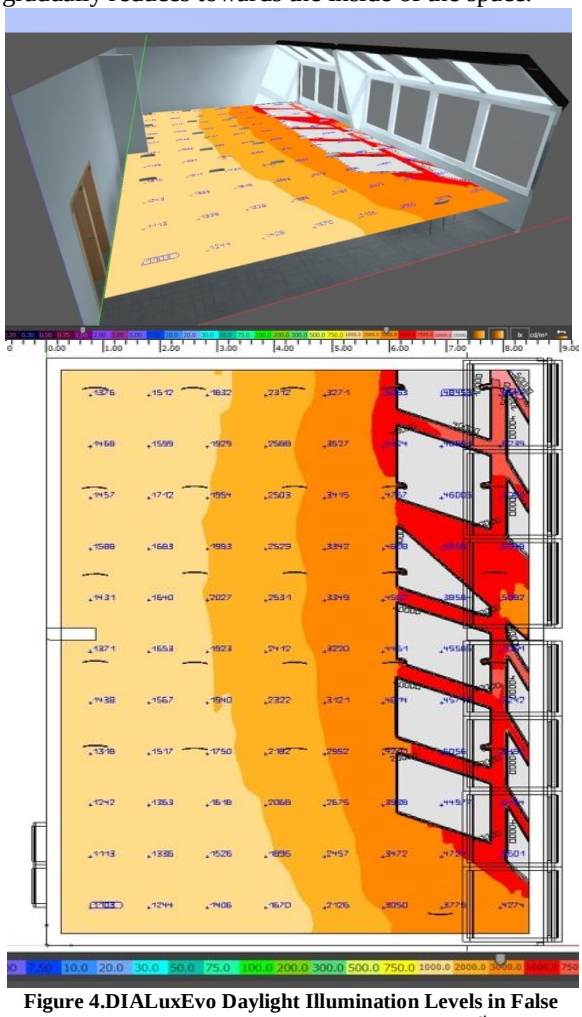


Figure 4.DIALuxEvo Daylight Illumination Levels in False Color Rendering - Clear Sky Conditions on the 21st March, 13:30 for the Existing Situation

CIBSE Lighting Guide for Education [16]and European standard EN 12464-1 [17] specifies the average perpendicular illuminance on the visual task area as 300-500 lx (lm/m^2). However, the calculated average illuminance is 2731 lx for the defined table surface. High WWR of the existing project (51%) cause excessive amount of daylight level on the work plane (average of 9274 lx). Moreover, interior shades that cover glazing areperceived to be inadequate to block daylight and heat gain from solar radiation. That means the daylight level for theclassroom does not meet the needs for visual comfort requirements unless direct sunlight is controlled.

D. Daylight Distribution with the Proposed Shading Device

Shading devices prevent interior to be exposed direct sun but allow penetrating diffuse light. In order to provide visual comfort conditions and prevent glare, external shading devices were incorporated with the existing glazing system of the classroom. Shading system was designed according to the Giovani bioclimatic chart and Olgyay's graphical method of "shading mask" also in consideration with the occupation time and function of the classroom. These steps were followed to design appropriate shading device in the case study:

1) Determining the important climatic periods according to the use of the classroom: (21 of March at 13:30 is selected for the daily shading period by depending on the occupation time of the educational unit)
2) Converting the information on the sun-path chart of the region(Latitude 40° - Bursa)
3) Overlapping the shadow angle protractor on sun-path chart to determine the shadow need period
4) Drawing the shading mask pattern
5) Determining the profile angle parallel and normal to the wall
6) Designing the sunshade according to shading mask pattern
7) Conducting daylight simulations according to input parameters

The classroom's fenestrationsystem provides visual contact with the outside world, which is pine forest, for the case building. Not to obstruct the green landscape with vertical shades, horizontal sunshades are attached above side and high clerestory windows on south-east facing walls. Yet, the system is supported with vertical operable louvres to control low sun angle penetration from the south-east orientation. The overhang profile angle was calculated approximately 50° normal and parallel to the wall and demonstratedin Fig. 5 and with the shading mask graphic in Fig. 6 respectively. The physical properties of the shading devices are given in Table IIItogether with Google Sketch-up perspectives of the classroom in Fig. 7.

Table III. Physical Properties of the Shading Devices

Type	Material	Dimension of each device	Number of Louvres	Surface Reflect.
Horizontal Overhangs (Side Windows)	Aluminum Panels	Panels 175x160 Louvres 50x 3cm	5 (rotation angle 45°)	80%
Inclined Overhangs (Clerestory Windows)	Aluminum Panels	Panels 175x160 Louvres 20x 3 cm	8 (rotation angle 0°)	80%

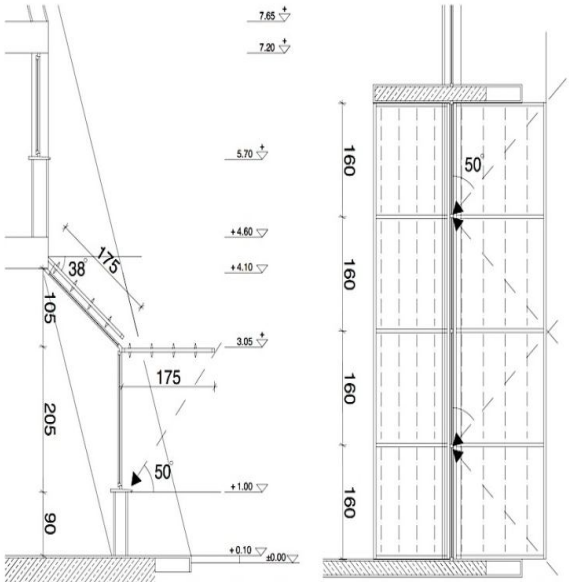


Figure 5. Determination of the Profile Angles Parallel and Normal to the External Wall

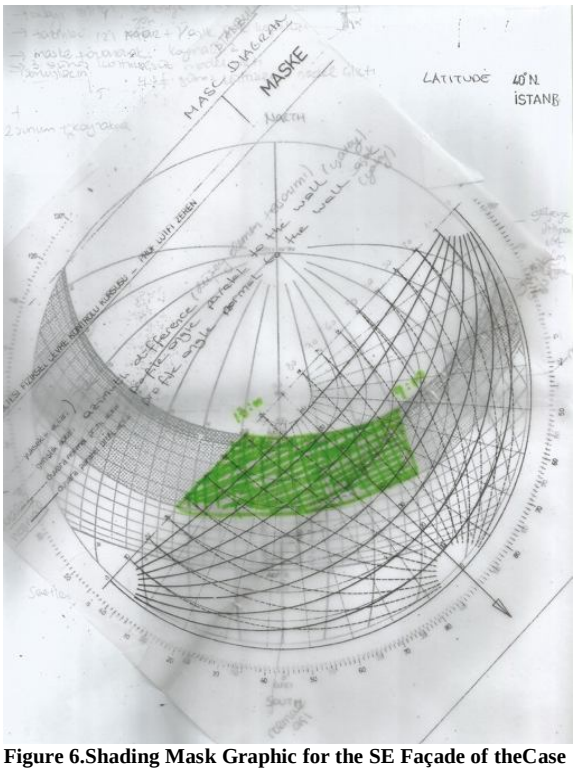


Figure 6.Shading Mask Graphic for the SE Façade of theCase Building (Northern Hemisphere, Latitude 40°, Operating Hours 09:00 – 18:00)

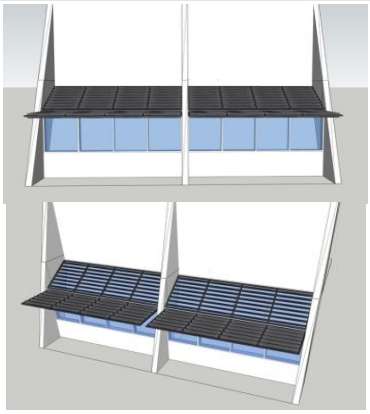


Figure 7. Sketch-up Perspectives of the Classroom Façade with Shading Devices

To prevent direct sunlight penetration into the classroom and to provide a more uniform day lit space simulation iterations are performed and the louvres rotation angle is determined due to this process (Fig. 8). Horizontal overhangs' louvres are set to 45° and inclined overhangs' louvres are set to 0° to obtain optimum results for the defined zenith luminance and clear sky (direct sunlight) conditions. The daylight performance of base case and proposed scenario results are given as illuminaceaverageEavg(lx), Emin(lx), Emax (lx) anduniformity as Emin/Eavgin Table IV. The calculations were carried out while lighting fixtures were switched off.

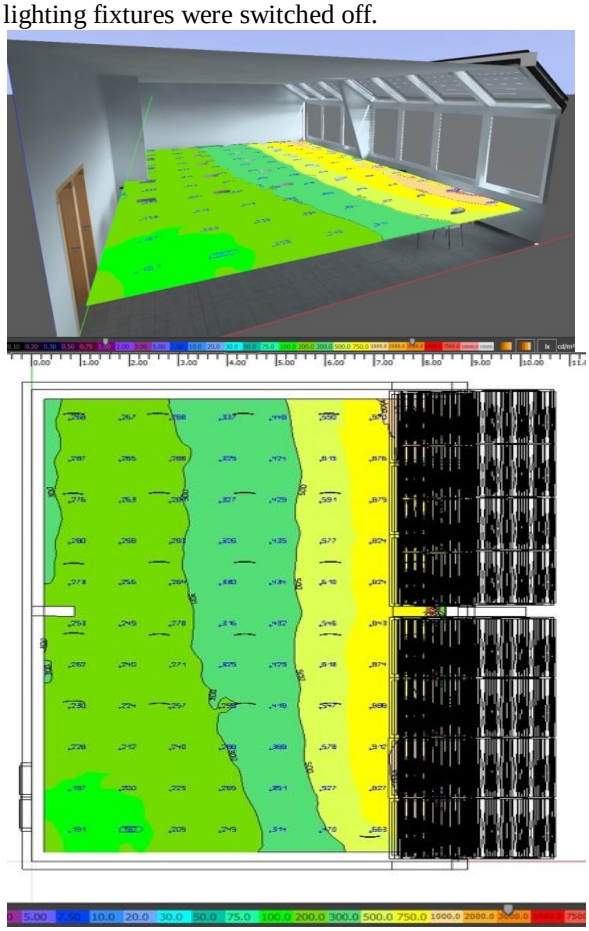


Figure 8.DIALuxEvo Daylight Illumination Levels in False Color Rendering - Clear Sky Conditions in March at 13:30 with Shading Devices

Table IV. Comparison of Existing Project and Proposed Daylight System with Shading Device

Existing Project	Eavg (Target) [lx]	Emin [lx]	Emax [lx]	Emin/Eavg
Workplane (h:0.8 m)	9274 (≥ 300)	1056	51391	0.11
Visual Task Area (h: 0.8; d:0.5x0.5m)	2731 (≥ 300)	2537	2945	0.93
Daylight factor affective area	9.890	2.700	24.332	0.27
Floor	6604	767	52721	0.12
Proposed System	Eavg (Target) [lx]	Emin [lx]	Emax [lx]	Emin/Eavg
Workplane (h:0.8 m)	338 (≥ 300)	183	3790	0.54
Visual Task Area (h: 0.8; d:0.5x0.5m)	426 (≥ 300)	390	460	0.92
Daylight factor affective area	1.333	0.511	3.213	0.38
Floor	359	6.79	30027	0.02

Results in Table IV, in general, were found to be better when compared to base case in terms of illuminance and uniformity. For horizontal overhangs on side windows and inclined overhangs on clerestory windows scenario, average daylight illuminance on the work plane (338 lx) and on the visual task area (426 lx) are closerto proper recommended level (300-500 lx) withthe existing fenestration transmittance value (70%).Shading device allows the penetration of direct sunlight and daylight in a controlled manner, thus the uniformity (Emin/Eavg)on the work plane is improved from 0.11 to 0.54.However, undesired illuminance of maximum 3790 lx isobtained near the windows despitethe retrofitting application which meansfurther precautions need to be integrated on the façade of existing educational building.

CONCLUSION

It has been crucial to benefit from daylighting and artificial lighting together as an integrated system to use energy efficiently and provide comfort during the day, since a well-designed lighting system increases learning and working performance in educational buildings. From this point of view, thisstudyaimstoachieve a bettervisualenvironmentfor a South-eastorientedclassroombydesigningarchitectural appendagesthatwillincorporatewiththeexistingfenestrationsystem. Olgyay'sShading Mask GraphicmethodalongwithDIAluxEvosimulationsare used to balance daylight and shade in the classroom for 21st ofMarchequinoxat 13:30. Based onthesekeyparameters of daylightingand solar shades, it is possibletooperatelouvres of overhangsbybuildingautomations in variableanglestorespondchanges in

daylightavailabilityandtoreducepotentialglareandheat gain in differentseasonsandoccupationhours. Thisongoingstudyonlyfocused onsolar shadingdeviceproperties. Daylightingresultsforretrofittingcan guidefordesigners, architectsandresearchers. Yet it is necessarytoconductsuch a studytointegratedlightingdesigncriteria ineducationalbuildings.Furtherretrofittingscenarioswil l be studiedfordifferentschedules (winterandsummersolstices), operatinghours (09:00, 15:00), skyconditionsandotherdesignparameterssuch asindoorsurfacecolours, fenestration, energyefficientlightingluminaries,lamps, (LEDs) andsensorsconnectedtotheshadingautomationsystems.

REFERENCES

[1] D. H. Li, S. L. Wong, C. L. Tsang and G. H. Cheung, "A Study of the Daylighting Performance and Energy Use in Heavily Obstructed Residential Buildings via Computer Simulation Techniques,"Energy and Buildings, vol. 38, pp. 1343-1348, 2006.

[2] D. H. Li, K. L. Cheung, S. L. Wong andT. L. Lam, "An Analysis of Energy-efficient Light Fittings and Lighting Controls," Applied Energy, vol. 87, pp. 558-567, 2010.

[3] T. G. Theodosiou,K. T. Ordoumpozanis,"Energy, Comfort and Indoor in Air Quality in Nursery and Elemantary School Buildings in the Cold CLimatic Zone of Greece,"Energy and Buildings, vol. 40, pp. 2207-2214, 2008.

[4] IEA, Daylight in Buildings, "A Source Book in Daylighting Systems and Components,"The Lawrance Berkeley National Laboratory, Berkeley: CA, 2000.

[5] A. Tzempelikos, A. K. Athienitis,"The Impact of Shading Design and Control on Thermal Performance of Building by TRNSYS Simulation," Renewable Energy vol. 23, pp. 497-507, 2001.

[6] D. Kesten, "Investigation of Efficient Lighting System Design in Educational Buildings at the Example "Municipal School of La Tour de Salvagny," Master's Thesis, Istanbul Technical University Institute of Science and Technology Department of Architecture Environmental Control and Building Technology Programme, Istanbul:Turkey, June 2006.

[7] L. L. Szepessy, "User Interaction with Environmental Control Systems in an Educational Office Building,"Dissertian, Vienna University of Technology Faculty of Planning and Architecture, Vienna: Austria, November, 2007.

[8] M. J. Holmes,J. N. Hacker, "Climate Change, Thermal Comfort and Energy: Meeting the Design Challenges of the 21st Century," Energy and Buildings, vol. 39, pp. 802-814, 2007.

[9] E. L. Krüger,A. L. Dorigo, "Daylighting Analysis in a Public School in Curitiba, Brazil," Renewable Energy vol. 33, pp. 1695-1702, 2008.

[10] R. K. Güvenkaya, M. Ş. Küçükdoğu, "An Approach to Determine Façade Options in Accordance with Different Orientations in Elementary School Classrooms from the Perspective of Lighting Energy Management,"ITU Journal Series A, Architecture, Planning, Design, vol. 8, pp. 77-88, September 2009.

[11] C. Ferreira,C. P.Soares, and P. Rocha, "Research on Energy Savings Potential of Daylighting in Tropical Climates: A Case Study of the Building Ibope, Brazil," 12th Conference of International Building Performance Simulation Association, pp. 1920-1925, Sydney 2011.

[12] L. Bellia,F. D. Falco, F. Minichiello, "Effects of Solar Shading Devices on Energy Requirements of Standalone Office Buildings for Italian Climates," Applied Thermal Engineering, vol. 54, pp. 190-201, 2013.

[13] Z. T. Kazanasmaz, P. F.Örs, "Modelling of Advanced Daylighting Systems to Improve Illuminance and Uniformity in Architectural Design," Master's Thesis, Izmir Institute of Technology the Graduate School of Engineering and Architecture, Izmir: Turkey, June 2013.

[14] I. E. Maestre,J. L. Blázquez, F. J.Gallero, P. R.Cubillas,"Influence of selected solar positions for shading device calculations inbuilding energy performance simulations," Energy and Buildings, vol. 101, pp. 144-152, 2015.

[15] Google. (n.d.). Retrieved September 13, 2017, from https://www.google.com/maps/search/uludagC4universitesi/

[16] CIBSE, Lighting Guide 05: Lighting for EducationLondon, UK, 2011.

[17] CEN, EN 12464-1 – Light and lighting – Lighting of work places – Part 1:Indoor work places, 2011. (All imagesand figures do not have a reference are taken from author's personal archive)

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