SIMULATION-ASSISTED DAYLIGHT PERFORMANCE EVALUATION OF AN EDUCATIONAL BUILDING IN A MEDITERRANEAN CLIMATE

S. Dervishi[1] and F. Jemini[1]
[1]Department of Architecture, Epoka University, Tirana, Albania

ABSTRACT

Utilization of natural light has been recognized to be valuable in achieving buildings with energy efficiency and in enhancing visual quality of interior spaces. This research evaluates the daylight performance of three-selected zone in an educational building in Tirana, Albania. The study explores the building geometry, orientation, glazing transmittance and window to wall ratio parameters on indoor daylight distribution. Radiance daylight software is used to simulate the horizontal illuminance (E) and high dynamic range luminance images (L) Simulation model incorporates detailed information of the building geometry, materials and transparency, to generate a finite-element simulation model.

INTRODUCTION

Daylight has always played a dominant role in human life, as an efficient, natural, renewable source of energy. It has a great impact in students' performance, creation of enjoyable settings, promotion of healthier environments (Boyce et al. 2013). The use of natural light in schools can ensure both physiological and physical benefits to pupils, teachers, administrators and working staff. Different studieshave proven the high significance daylight has on human productivity, health and wellbeing (Houck 2015, Heschong et al. 2002, Dumont & Beaulieu 2007, Küller et al. 2006) Moreover, in educational environments, good daylight has a great impact on learning outcomes of the students, as well as in the attendance rates (Haverinen-Shaughnessy et al. 2015). In addition, good daylighting in schools helps in providing good vision for performing any task comfortably and easily for both students and teachers. Evidentially, it is impossible for students to study with inadequate lighting (Boyce 2010). The distribution of sufficient and adequate light in the workplace desk and blackboard, affects not only the visual comfort but also the concentration of students (Dudek 2007).

As such, this research aims to examine the daylight performance of a faculty building, Epoka University in Tirana, Albania. The study analyses the daylight performance in selected classes and office space and evaluates the daylight parameters which would provide adequate visual comfort. Annual illuminance levels, daylight factor, daylight autonomy are explored via Radiance computational simulation model. In addition, survey data gathering is used to explore occupant's daylight comfort of indoor spaces.

METHODOLOGY

This study evaluates the daylight performance of selected classrooms and identifies the typologies and parameters which provide adequate daylight illuminance. The study is conducted based on the data collection from the class layouts, the window size and transparency information. Daylight computational simulation analysis is used to predict illumination, visual quality and evaluate daylighting performance. The investigated time is between 09:00hrs am to 17:00hrs pm, during four discrete days of the year: 20th March, 21st of June, 22nd of September and 21st of December. Perez sky model (Perez et al. 2003) is used to generate the sky illuminance model. For the purpose of this study, RADIANCE simulation software (Ward 1994) is used to perform simulations for daylight illuminance levels in the classrooms.

Case Study Description

Three zones located at Architecture and Engineering faculty building at Epoka University in Tirana, Albania, are selected in order to evaluate the daylight performance. The selection criteria of classrooms is based on geometry, materials, window typology, WWR and orientation. The zones are positioned in North-West South and North-East orientations. The window to wall ratio (WWR) varies from 30% to 70%. Spaces are evaluated under various skies (e.g. overcast, clear). Each test spaces have a reconfigurable window wall facing due north-east, north-west and south orientation respectively. Figure 1 shows the floor plan of the interior organization of the spaces in the building. The selected classrooms are located on the 1st floor. The glazing of the selected zones is double pane low E glazing (with normal luminous reflectance of 0.1 and 72% light transmittance). A luminance Meter LS-150 was used to measure the surface brightness (see table 1)

 DOI: 10.3217/978-3-85125-786-1-43

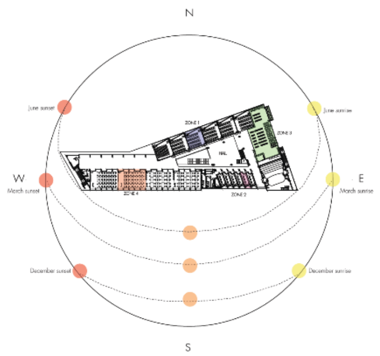

Figure 1: Floor plan of the building that identifies the spaces used for analysis.

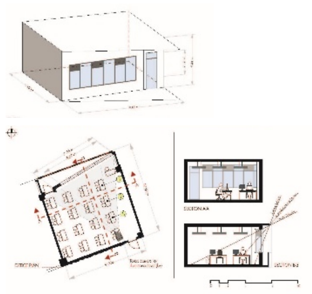

Figure 2: Geometric properties in plan, section and 3D view of Zone 1 (Classroom).

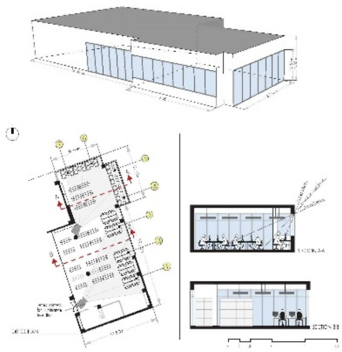

Figure 3: Geometric properties in plan, section and 3D view of Zone 2 (Library).

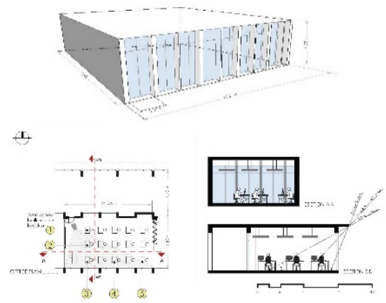

Figure 4: Geometric properties in plan, section and 3D view of Zone 3 (Architectural Studio).

– Zone 1 *(Classroom)*

The zone 1 *(Classroom)* faces North-West direction. The windows are placed in the centre of the wall, in order to maintain a view to outside. The window to wall ratio (WWR) is 40%. Figure 2 illustrates the geometry (plan, section, 3D view) including the grid workstation points used for daylight evaluation.

– Zone 2 *(Library)*

The Zone 2 *(Library)* library facing North-East direction, dimensions and location of view, have been described with real existing conditions in the following drawings. The Window to Wall Ratio (WWR) is 70%. Figure 3 illustrates the geometry (plan, section, 3D view) including the grid points used for daylight evaluation.

– Zone 3 *(Architectural Studio)*

The large classroom *(Architectural studio)* faces South direction with a Window to Wall Ratio (WWR) of 90%. The transparency has been considered to maintain a view to outside. Figure 4 illustrates the geometry (plan, section, 3D view) including the grid points used for the daylight evaluation.

Table 1: Configuration of selected spaces

	ZONE 1	**ZONE 2**	**ZONE 3**
Geometry	9.00 x 10.0 x 4.35 m	15.35 x 11.0 x 4.35	15.35 x 11.0 x 4.35 m;
Orientaiton	north west	south	north east
Reflectance	Ceiling 0.80, wall 0.7 floor 0.4	Ceiling 0.80, wall 0.75 floor 0.4	Ceiling 0.80, wall 0.75 floor 0.4
Window Size	6.60 x 2.10 m sill height 1.00 m	5.35 m x 4.00 m sill height at floor level	5.35 x 4.00 m sill height at floor level
Glazing property	Double Glazing, $T_{vis} = 0.70$	Double Glazing, $T_{vis} = 0.70$	Double Glazing, $T_{vis} = 0.70$

Simulation

RADIANCE Simulation software is used to predict workstation horizontal illuminance (E) at various locations in space and high dynamic range luminance images (L). Simulation model incorporates detailed information of the building geometry, materials and transparency to generate a finite-element simulation model (see table 1). Perez et al. (1993) sky radiance model which uses clearness index as a classification criteria of the skies is used for to generate sky luminance maps. Studies have indicated that Perez all weather sky model has shown high accuracy (Dervishi and Mahdavi 2012, Orehouning et al. 2014, Dervishi and Mahdavi 2013). The hourly simulations are run over the same height (75 cm above the floor plane) and are performed during the autumnal and vernal

DOI: 10.3217/978-3-85125-786-1-43

equinoxes (21st September & 21st March) and summer and winter solstices (21st June & 21st December) from 9:00 am to 17:00 hours, local time. Each of the 48 resulting sky conditions are generated by the GENDAYLIT Radiance program utilized by the PEREZ all weather sky. The diffuse fraction of solar irradiance is derived by Perez Model (Dervishi and Mahdavi 2013).

The point locations of the workstation to compute the horizontal illuminance (E) are illustrated as per Figures 3 to 5 for each space. Furthermore, detailed high dynamic range luminance images were generated for the four discrete days of the year: The radiance imput parameters are detailed in Table 2.

Table 2:
Radiance simulation input parameters

SIMULATION PARAMETER	VALUE
Ambient bounces (ab)	4
Ambient divisions (ad)	1024
Ambient sampling (as)	20
Ambient accuracy (aa)	0.22
Ambient resolution (ar)	512

RESULTS AND DISCUSSION

– Zone 1 *(classroom)*

Figures 6 and 7 illustrate the computed horizontal illuminance levels of Zone 1 (classroom) for four reference days. Whereas, figure 8 and 9 illustrate the RADIANCE illuminance images (E, lx) and high dynamic range luminance images (L, cd/m2) respectively.

As the figures illustrate, the daylight levels are rather low (mainly diffuse light) for the reference days in September, December and March resulting in low comfort and productivity. During these reference days, windows provided higher daylight levels during the period 10:00 am to 13:00 pm with illuminance level ranging between 416 to 537 lux. As the classroom is oriented towards the North West direction, during summer solstice month (21st of June), illuminance level are exposed to direct daylight only after 15:00 with illuminance level between 904 – 1247 lux (see figure 12). Figure 13 shows a set of false colour luminance images depicting the distribution and intensity of redirected sunlight between 09:00 am to 17:00 pm for the reference days. During summer solstice, luminance levels of the zones near the window are significantly greater. Average ceiling zone luminance peaked at about 3000 cd/m2 during summer solstice. Peak levels are lower during equinox and Winter solstice periods, 750.25 cd/m2-1900 cd/m2, respectively.

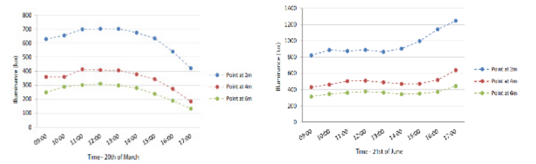

Figure 5: Workplace Illuminance levels of selected virtual sensors of Zone 1 for 20th of March (left) and 21st of June (right)

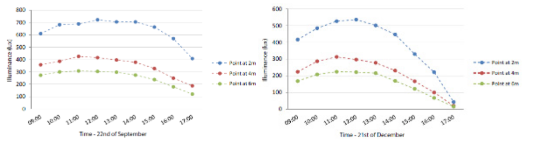

Figure 6: Workplace Illuminance levels of selected virtual sensors of Zone 1 for 22nd of September(left) and 21st of December (right)

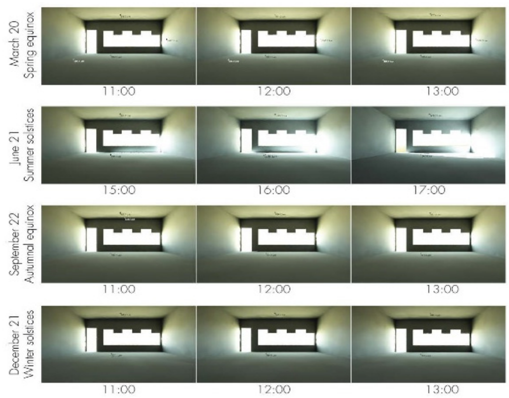

Figure 7: Rendering in Radiance Simulation calculations showing luminance levels (candela/m²) at 2.0 m distance from window of Zone 1 for four reference days (20th of March, 21st of June, 22nd of September, 21st of December)

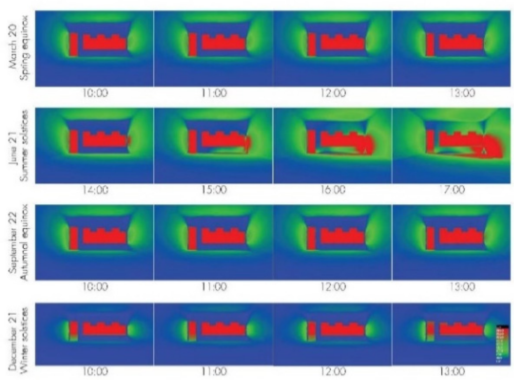

Figure 8: Falsecolor luminance images (cd/m²) of Zone 1 for four reference days (20th of March, 21st of June, 22nd of September, 21st of December)

 DOI: 10.3217/978-3-85125-786-1-43

– Zone 2 *(library)*

Figures 9 and 10 show the computed horizontal illuminance levels of Zone 2 *(library)* facing North-East orientation for four reference days. Whereas, figure 11 and 12 illustrate the RADIANCE illuminance images (E) and high dynamic range luminance images (L) respectively.

As figures show, workplaces near the windows are highly exposed to daylighting in summer solstice (on 21st of June) which tend to be not comfortable. The illuminance levels range from 1206 to 19570 lux. However, during the spring and autumnal equinox (20th of March and 21st of September) and winter solstice (21st of December) the zone is highly exposed to direct light from 09:00 am to 10:00 am, while during the other hours the daylight levels are considerably reduced. Average ceiling zone luminance peaked more than 3000 cd/m^2 during the summer solstice. As expected, peak levels are lower during autumnal, spring equinox and winter solstice periods, ranging from 755.6 cd/m^2-3000 cd/m^2.

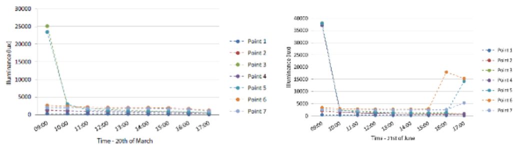

Figure 9: Workplace Illuminance levels of selected virtual sensors of Zone 2 for 20th of March (left) and 21st of June (right)

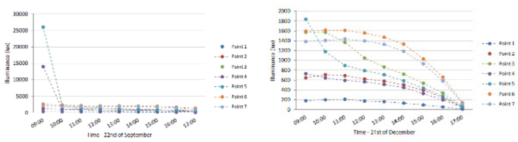

Figure 10: Workplace Illuminance levels of selected virtual sensors of Zone 2 for 22nd of September(left) and 21st of December (right)

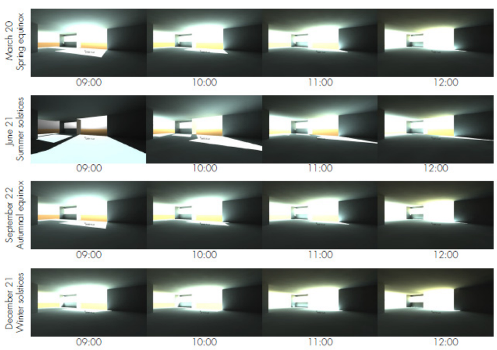

Figure 11: Rendering in Radiance Simulation calculations showing luminance levels (candela/m^2)at 2.0 m distance from window of Zone 2 for four reference days (20th of March, 21st of June, 22nd of September, 21st of December)

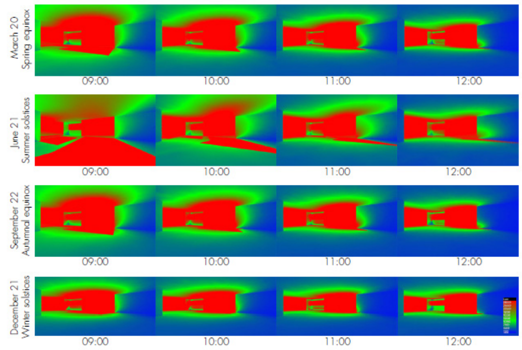

Figure 12: Falsecolor luminance images (cd/m^2) of Zone 2 for four reference days (20th of March, 21st of June, 22nd of September, 21st of December)

– Zone 3 *(architectural studio)*

Figures 13 and 14 illustrate the computed horizontal illuminance levels of Zone 3 *(architectural studio)* facing South orientation for the four reference days. Whereas, figure 15 and 16 illustrate the RADIANCE illuminance images (E) and high dynamic range luminance images (L) respectively.

Simulated horizontal illuminance levels during four discrete days of the year are considerably high from morning 09:00 am until noon 16:00 pm. In summer solstice day (21st of June) close to the windows, with illuminance between 2750 to 3718.7 lx. For the other reference days, illuminance values range from 2660-39750 lux, exposed to the zone's deep surface. Average ceiling zone luminance peaked more than 3000 cd/m^2 during the Summer solstice day. Peak levels resulted lower during the other reference days ranging from 2020 cd/m^2 more than 2850 cd/m^2.

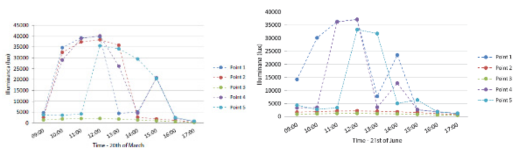

Figure 13: Workplace Illuminance levels of selected virtual sensors of Zone 3 for 20th of March (left) and 21st of June (right)

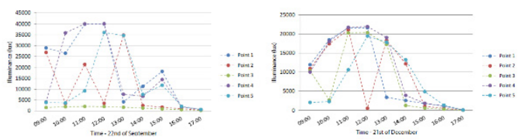

Figure 14: Workplace Illuminance levels of selected virtual sensors of Zone 3 for 22nd of September(left) and 21st of December (right)

DOI: 10.3217/978-3-85125-786-1-43

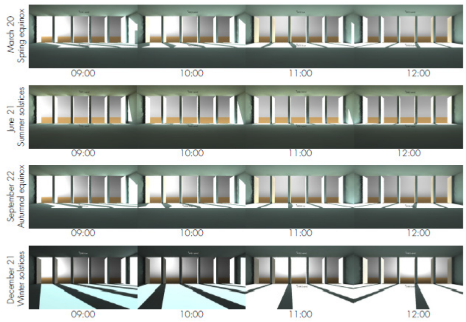

Figure 15: Rendering in Radiance Simulation calculations showing luminance levels (candela/m^2)at 2.0 m distance from window of Zone 3 for four reference days (20th of March, 21st of June, 22nd of September, 21st of December)

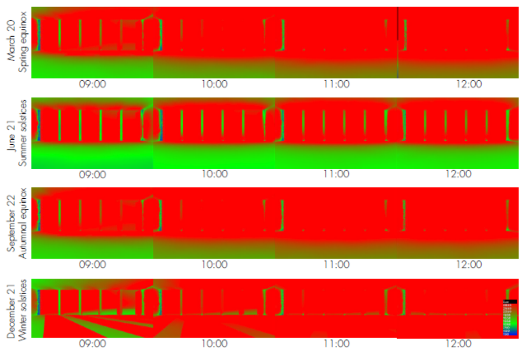

Figure 16: Falsecolor luminance images (cd/m^2) of Zone 3 for four reference days (20th of March, 21st of June, 22nd of September, 21st of December)

OPTIMIZATION

Daylight availability was analyzed for the three zones facing North-West, North-East and South orientation respectively. Overlit areas reached more than 70% in Zone 3 (South orientation), followed by 53% in Zone 2 (North-East orientation) and 42% in Zone 1 (North-West orientation). However, no partially daylit areas were anticipated in South oriented zone space, effected by window size (WWR 90%) and glazing properties (see table 1). The layout design of zones 3 *(Architectural Studio)* shows that the working environment lacks daylight comfort. As such, a slat angles exterior horizontal shading system with aluminium reflective material is proposed. The proposed design of exterior shading device is modelled at a distance to the outer glass layer. The proposed design of exterior shading aims at minimizing glare and reducing the daylight levels in indoor areas during clear skies in hot seasons. Figure 17 and 18 illustrate the geometry of the exterior shading and the application in the façade system of Zone 3. Table 3 illustrates the variations of slat angle shading design.

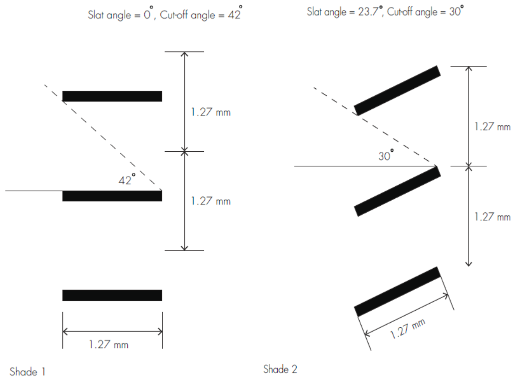

Figure 17: Geometry of the proposed exterior slat shades

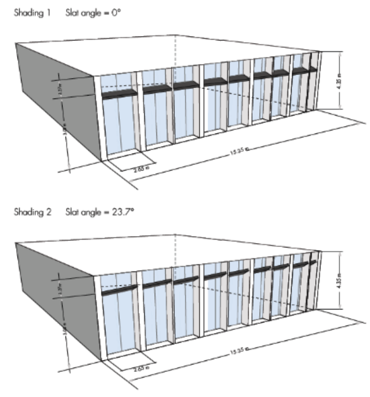

Figure 18: Facade elevation with the slat angle 0° and 23.7° shading design proposal of Zone 3 (South direction).

Table 3:
Variations of slat angle shading design.

Shading system	Shading 01	Shading 02
Slat angle (degree)	0	30
Cut-off angle (degree)	45	30
Ratio: slat width to spacing	1:1	1:1

Figures 19 and 20 illustrate the computed horizontal illuminance levels of Zone 3 *(architectural studio)* with the use of shading systems with slat angle 0° and 23.7° respectively. As figures illustrate, the use of shading devices reduces considerably the daylight levels in summer solstice *(21st of June)* of workspaces. The slat shading angle of 0 ° results to perform better than slat shading angle of 23.7°, reducing considerably the horizontal illuminance to required level. Furthermore, luminance peak levels (Summer solstice

 DOI: 10.3217/978-3-85125-786-1-43

day) are reduced with a range of 1730 cd/m² to 2002 cd/m² (see figure 21 and 22).

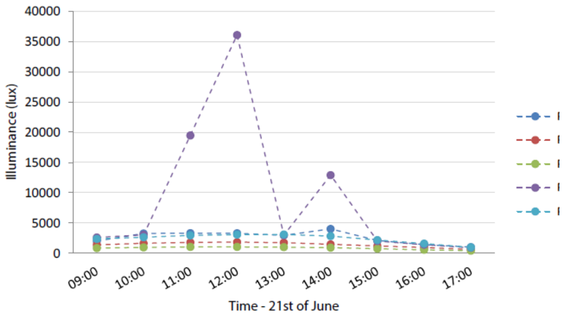

Figure 19: Workplace illuminance level for June sosltice month (21st of June) with exterior slat shading angle = 0 °

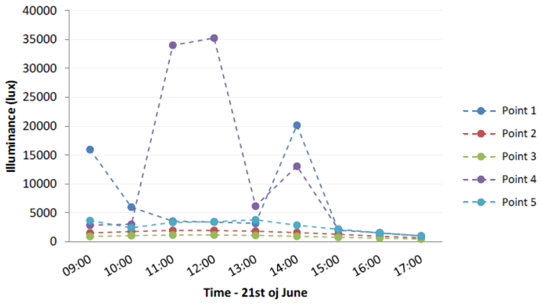

Figure 20: Workplace illuminance level for June solstice month (21st of June) with exterior slat shading angle 23.7 °.

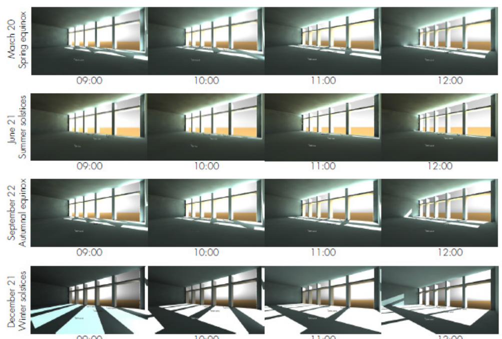

Figure 21: Rendering in Radiance Simulation calculations showing luminance levels (candela/m²)at 2.0 m distance from window of the optimized scenario (slat shading angle of 0 °) for four reference days (20th of March, 21st of June, 22nd of September, 21st of December)

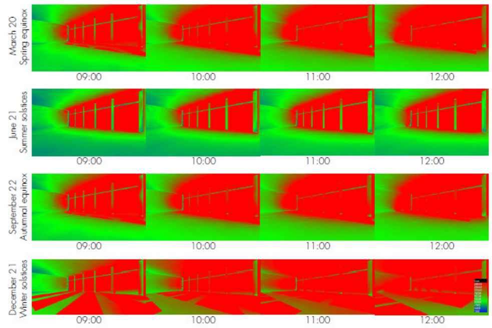

Figure 22: False color luminance images (cd/m²) of the optimized scenario (slat shading angle of 0 °) for four reference days (20th of March, 21st of June, 22nd of September, 21st of December)

CONCLUSION

Natural light is a crucial component for the quality of indoor environment. The behavior of occupants working in spaces and their organizational outcomes in terms of comfort, productivity, health and well-being are highly influenced by the quality of light in indoor environment. Daylight utilization in educational buildings can be improved while enhancing the natural indoor working quality and saving lighting consumption. Many significant factors influence the daylight performance including orientation, geometry, materials, window to wall ratio (WWR, %), glazing properties and the appliance of shading systems.

This research investigates the daylight performanc of three zones located at Epoka University in Tirana, Albania. The horizontal illuminance levels and high dynamic range luminance images are explored via computational simulation. The selection criteria of classrooms is based on the geometry, materials, window typology, WWR and orientation. Spaces are evaluated under different sky (e.g. overcast, clear sky) conditions. The study showed that, Zone 3 performs the worst with considerably high illuminance levels. A shading control design was implemented to the facade in order control and potentially reduce the strong daylight during the Summer solstice months.The two proposed slat shading angle 0° and 23.7° were tested in zone (Architectural Studio) facing south direction. The results showed that the slat shadings angle 0° performed better to the reduction of illuminance level (lux) of a daylit space during the strongest daylight in summer solstice (21st June). The simulations carried out in this research show that the performance of a building could be controlled and examined since the very first stage of design. This investigation therefore intends to increase awareness on the elemental role daylight has as the main feature of quality learning spaces. Additionally, the study emphasizes the aspects of design, that are substantially indispensable for good daylighting in educational buildings.

DOI: 10.3217/978-3-85125-786-1-43

REFERENCES

Baker N. V., Fanchiotti, A., &. Steemers, K.1993. Daylighting in Architecture: A European Reference Book.

Boyce, Peter. 2013. Lighting Quality for All. CISBE & SLL International Lighting Conference - Dublin 2013. Session 3. ISSN 03606325

Boyce, Peter R. 2010. Review: The impact of light in buildings on human health. Indoor and Built Environment. DOI: 10.1177/1420326X09358028

Dervishi S, Mahdavi A. Computing diffuse fraction of global horizontal solar radiation: A model comparison, Solar Energy, 86 (2012), 6; 1796 - 1802.

Dervishi S., Mahdavi A. A simple model for the derivation of illuminance values from global radiation data, Building Simulation, 6 (2013), 4; 379 - 383.

Dervishi, Mahdavi. 2013: "A model to estimate luminous efficacy of global solar radiation for all sky conditions". CLIMA 2013. 11th Rehva World Congress &8th International conference on IAQVEC. 16-19. 06. 2013. Prague, Czech Republic.

Boyce, P. 2003. Human Factors in Lighting, 2nd edition. New York, USA: CRS PRESS.

Boyce, P., Hunter, C., & Howlett, O. 2003. The benefits of daylight through windows. New York: Report, Lighting Research Center, Rensselaer Polytechnic Institute.

Dudek, M. 2007. A Design Manual: Schools and Kindergartens. Birkhauser, 250.

Dumont, M., & Beaulieu, C. 2007. Light exposure in the natural environment: Relevance to mood and sleep disorders. Sleep Medicine, 557-565.

Haverinen-Shaughnessy, U., Shaughnessy, R., Cole, E., Toyinbo, O., & Moschandreas, D. 2015. An assessment of indoor environmental quality in schools and its association with health and performance. Built Environment, 35-40.

Heschong, L., Wright, R. L., & Okura, S. 2002. Daylight impact on Human Performance in School. Journal of the Illuminating Engineering Society.

Houck, L. 2015. A novel approach on assessing Daylight access in Schools. 8th Nordic Conference on Construction Economics and Organization (pp. 40-47). Tampere, Finland: Elsevier.

Küller, R., Ballal, S., Laike, T., Mikellides, B., & Tonello, G. 2006. The impact of light and colour on psychological mood: a cross-cultural study of indoor work environments. Ergonomics in Design, 1496-1507.

Orehounig K., Dervishi S., Mahdavi A.: Computational derivation of irradiance on building surfaces: An empirically-based model comparison, Renewable Energy, 71; 185– 192

Perez R, Seals R, Michalsky J. 1993. All weather model for sky luminance distribution—preliminary configuration and validation. Solar Energy, Vol: 50 (3), pp: 235–245.

Ward, G. J. 1994. The RADIANCE lighting simulation and rendering system. In SIGGRAPH '94: Proceedings of the 21st Annual Conference on Computer Graphics and Interactive Techniques, pages 459–472. ACM Press.

 DOI: 10.3217/978-3-85125-786-1-43