Armanshahr Architecture & Urban Development, 10(18), 83-97, Spring 2017

ISSN: 2008-5079

EISSN: 2538-2365

The Impact of Tilting Northern Open Space Wall on Daylight Performance of Residential Buildings

Soha Golafshan[1*] and Mohammad Sajad Shahin[2]

[1] Ph.D. Student of Architecture, Architecture and Urban Design School, Art University of Isfahan, Isfahan, Iran.

[2] B.Sc. Student of Civil Engineering, Department of Civil Engineering, Isfahan University of Technology, Isfahan, Iran.

Received 28 February 2016; Revised 17 July 2016; Accepted 17 September 2016

ABSTRACT: A northern open space (NOS) is built in some residential buildings to enhance daylight performance of indoor spaces which do not access to yard or other open spaces. Compliant with the urban standards of Iran, NOS must be partitioned from the adjoining yard by a tall wall. Economically, for increasing the usable residential area, the NOS width is often limited to the minimum of urban standards. A typical residential building located in the densely-built Mardavich area was selected as a case. This paper, using daylight simulation, calculates and compares the impact of two variables on the illuminance level of indoor spaces: the NOS width and the angle of NOS southern wall. For this end, the illuminance levels of the indoor space were measured and at different conditions: three widths of NOS (2, 3, and 4 m) with the vertical southern wall, minimum width of NOS (2 m) with four tilted southern walls (5, 10, 15, and 20 degree). The daylight simulation at winter solstice was conducted for estimating the minimum daylight level and the daylight simulation at summer solstice was conducted for predicting the potential glare. The results of this study show that tilting the southern wall of NOS (facing to indoor space), allocating a smaller area to the NOS, increases the total usable space area of residential buildings and improves its daylight performance; Based on these results, this paper recommends a novel strategy for architects to enhance the daylight performance of NOS by creating semi- funnel shape for NOS.

Keywords: Daylight Performance, Illuminance Level, Northern Open Space, Tilted Wall, Honeybee.

INTRODUCTION

Buildings are major consumers of energy and account for about 30 to 40 percent of the total energy consumption of developed countries (Zawidzki, 2015). Further, 20 to 30 percent of the total energy consumed in buildings is currently being used to provide lighting (Yun et al., 2014). Studies shows that daylighting can be a cost-effective alternative to electrical lighting for commercial and institutional buildings (Ihm et al., 2008). Therefore, implementing efficient daylighting designs can play a significant role in reducing fossil fuel consumption. Besides, daylight is a key environmental contributor to the residents' physical and psychological well-being. The unique feature of daylight is its hourly and seasonal variations. Unlike artificial light, natural light has a dynamic and variable nature linking the residents with the outside world by providing a sense of hourly, daily, or seasonal change. Reinhart and Galasiu (2006) determine five definitions for daylighting from five different aspects. From architectural side, it defines as: "the interplay of natural light and building form to provide a visually stimulating, healthful, and productive interior environment". Thus, a proper daylighting design provides thermal and visual comfort and consistency in the environment along with consequential improvement of mental well-being of the residents (Ghiabaklou, 2013). Now, there are two paradigms that measure daylight, useful daylight illuminance (UDI) and daylight factor (DF). DF is a single number (as a percentage) for each point in a space. In contrast, a climate-based analysis results in an illuminance prediction for every daylight hour of the year for each point considered (Nabil, 2012).

Uncontrolled increase in real-estate development in the central parts of Iran has led to longitudinal elongation of land lots and resulting poor daylighting potential. According to the rules and regulations cited in the Isfahan

* Corresponding Author Email: s.golafshan@aui.ac.ir

urban plan, the structure of the house should occupy no more than 60% of the total area of the land lot, and it should be built upon the northernmost part of the plot (Isfahan.ir, 2015). The extreme north-south elongation of land plots due to the large distance between the parallel access roads and the emphasis of municipalities on dedicating a certain fixed area to all land plots means that buildings located at the northern end of the roads can receive daylight only from their narrow southern face. The standard solution to this problem is to add a NOS (Northern Open Space) at the northern end of the plan; but to ensure the privacy of neighbors, the urban development standards have forbidden windows overlooking the yard of an adjoining northern neighbor, so a wall as high as the height of the building must be built in that position. Building this NOS patio reduces the marketable area of the house; therefore, land developers often seek to limit the area of the patio to the minimum value dictated by the law, causing inadequate daylighting at the northern spaces of the house. There are two major factors contributing to the daylight efficiency of the NOS: the NOS width and the angle of wall between NOS and indoor space.

Impacts on daylighting performance are investigated for several combinations of building geometry, window opening size, and glazing type (Krarti, 2004). Thus far, the role of urban envelopes in fulfilling the lighting requirement of residential buildings has been the focus of several studies. These involve a study where the author has assessed the impact of the street width on the shading and lighting of the building (Tahbaz, 2009). Another research has targeted the role of Atrium Architecture geometry on the daylighting performance (Du et al., 2010). Rezwan (2015) has addressed the role of atrium proportion in providing sufficient daylight. Arab (2012) has measured lighting performance of a single dome by using 3DStudio Max Design software. However, this paper is a pioneer study on the role of tilted walls in the daylighting efficiency of the NOS in residential buildings.

RESEARCH METHODOLOGY

Selection of a Case Study

Since this paper focuses on the impact of NOS on daylight reception of residential units, a residential neighborhood in highly densely-built urban zone which involves many regular geometrical plots without enough daylight is selected as a case to answer the research questions. Its location is in Mardavich area of Isfahan. Their sole transparency possibility from limited southern side make them have a NOS space in their northern part. As Figure 1 shows, several factors such as the fixed distance between the roads, the need for providing an access road to all the land plots, and emphasis of municipalities on dedicating an approximately fixed area to all the land lots have caused the land plots to face with an extremely elongated shape in the north-south direction (Fig. 1).

According to municipal regulations, the buildings in this area are allowed to have up to five floors. Fig. 2 shows the location of the NOS in the plan of residential case. This building has 5 floors of 10 m ×10 m × 15 m (Fig. 2). In this study, sensor points are positioned from window facing to the NOS to 5 meters away. Regarding occupants' life style, work plane is considered on the floor. The height of widow is 2.70 m which is located on the floor.

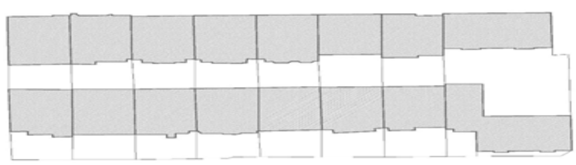


Fig. 1. Plan of Neighborhood Units of Mardavich, Isfahan

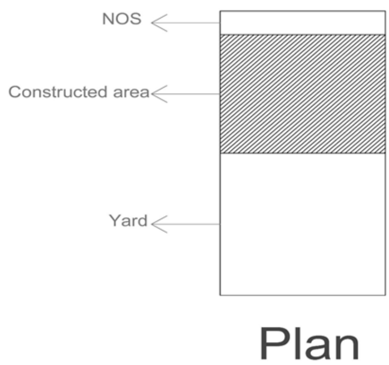


Fig. 2. NOS Location in Plan

Evaluation Factors

This paper seeks to improve the daylighting efficiency of the NOS by changing two parameters in its geometry; those that can have a significant impact on the daylighting are the (north-south) width of NOS (D) and the tilt of northern wall facing the patio (α) (Fig. 3).

To protect the visual privacy of the northern neighbors, current regulations cited in the detailed urban plan for this area have set the minimum length of the NOS at 3 meters (Isfahan.ir 2015).

The hypothesis of this study is that tilting the NOS wall (between NOS and indoor space) can help improve the illuminance level received by indoor space; thus, this approach can be used to fulfill the need for increased width of NOS. To examine the hypothesis, we first studied the impact of the changes in the width of NOS on its daylighting efficiency. This was done by daylight simulation for the models with 2-m, 3-m and 4-m width of NOS. At the second stage, the divided wall in the NOS with the minimum allowed width (2 meters) was tilted by 5, 10, 15, and 20 degrees (Fig. 3), and the results of daylight simulation were examined. The results were also compared with those of the previous stage. Figure 3 shows an overview of the different cases.

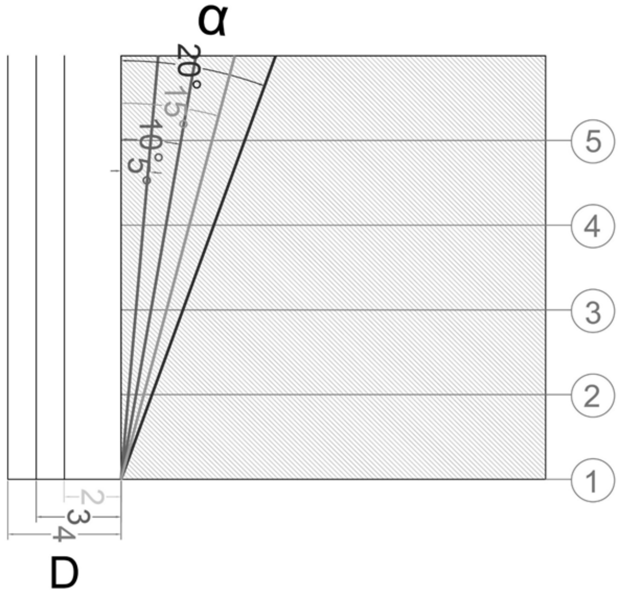


Fig. 3. The Width of NOS (D) and the Tilt of Northern Wall Facing the NOS (α).

To compare the NOS daylight performance of these cases it is necessary to calculate the total area that allocated to NOS (A) for any case. It clarifies that in each case how much area of NOS provides which illuminance level for indoor spaces. It can be calculated with following equation:

$$A: \quad 10 \sum_{n=0}^{4}(2 + 3n \tan\theta)$$

A: Area Allocated to NOS

θ: Tilted wall angle with Z axis

10 m: NOS length

2 m: minimum NOS width

3 m: residential unit height

The effect of parameter D on indoor daylighting was examined for the most critical daylight condition which occurs in the winter solstice; thus, simulations were conducted at ten o'clock in the morning of December 21st.

On the other hand, excessive exposure to daylight may cause glare and threaten the occupants' visual comfort; therefore, all the simulations were repeated for ten o'clock in the morning of the summer solstice. In accordance with the previous study, 3000 lx was considered as the glare threshold (Hashemloo & Inanici 2015), (Yun et al., 2014).

Form-generating and Analysis Tools

There are some daylight simulation tools which can be applied for this research. A combination of several parameters prompted the use of parametric simulation platforms. In this study, the daylight simulation software was to assess the amount of daylight received through the NOS for different widths and tilts of the wall. The application used for this purpose was Honeybee parametric simulation software which simulates the daylight while taking the hourly climatic data of the region into consideration. The software is an open source and works on the parametric environment of Grasshopper, a graphical programming tool for Rhinoceros which is a 3D modeling software. It allows the designer to determine the effect of the plan and form of buildings on the amount of daylight and energy consumption during the design stages. The Ladybug + Honeybee processes are provided by the Radiance runs (Roudsari & Pak, 2013). The software uses the climatic data of the target area parametrically for the simulation (Table1). In this study, the climatic file of the Isfahan city[1] (40-year average) with an EPW format was entered into the software. Regarding to the Isfahan climate, simulations were performed using the CIE standards clear-sky condition for each date and time.

Table 1. Software Used for 3D Modeling, Analysis, and Simulation

Platform	Utilization
Rhinoceros	3D Modeling
Grasshopper	Parametric Modeling, Data Analysis
Ladybug + Honeybee	Daylight Simulation

Table 2. Defined Material Property for Simulation

Object	Material Property For Simulation
Outside Facade	Roughness= 0.1, Specularity= 0.05
Glazing	85% Transmittance

Data Evaluation Criteria

This paper uses the illuminance level to evaluate the daylight requirements of the spaces. Illuminance is the total luminous fluxes received per unit surface area and measured in lx. Published articles suggest that any daylight illuminance in the range 100 lux to 2000 lux should be considered as offering potentially useful illumination for the occupants of the space (Nabil, 2012).

Previous studies have provided the standard illuminance required by different spaces in accordance with their usage [10]. These standards are shown in Table 3.

Table 3. Recommended Illuminance for Typical Activities in Residential Buildings

Activities	Recommended Illuminance (Lx)
Cooking	200
Work Requiring Perception of Detail	500
Reading, Writing	300

(Lu et al., 2016)

In the plans of residential buildings located in the study area, spaces adjacent to the NOS are often bedrooms, reading rooms or kitchens, which according to the above table require an illuminance of about 300 lx.

DAYLIGHT SIMULATION

Daylight Simulation for Winter Solstice (December 21st)

Daylight simulation for the winter solstice was carried out to evaluate the illuminance level of the indoor spaces in the northern part of the building which uses the daylight provided by the NOS. Each layer in each simulation is one meter (Table 4 & 5).

Table 4. Daylight Simulation with Honeybee for Vertical Wall for December 21st

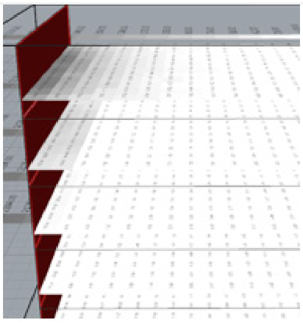
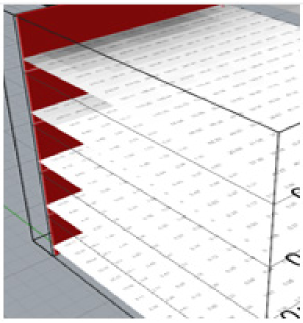
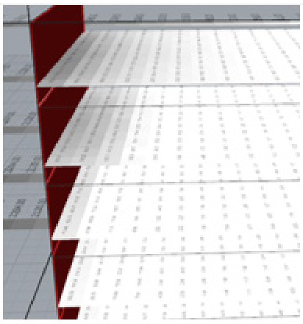
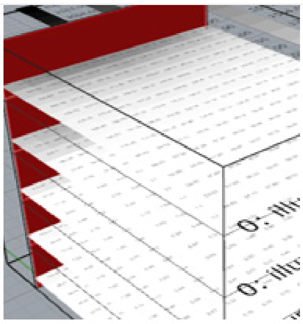
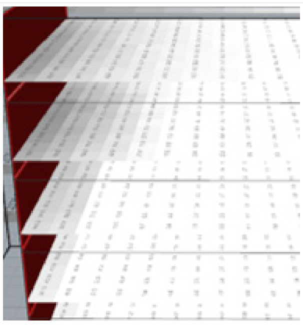
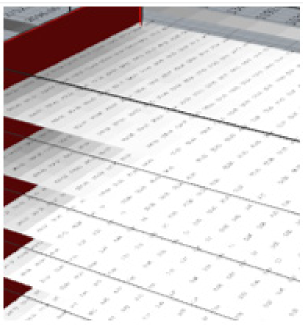
	Cases	Area Allocated to NOS (A)	Daylight Simulation with Honeybee		
Daylight Simulation for Winter Solstice (21st December)	2-m NOS width & vertical wall	100 m^2			
	3-m NOS width & vertical wall	150 m^2			
	4-m NOS width & vertical wall	200 m^2			

Table 5. Daylight Simulation with Honeybee for Tilted Wall for December 21st

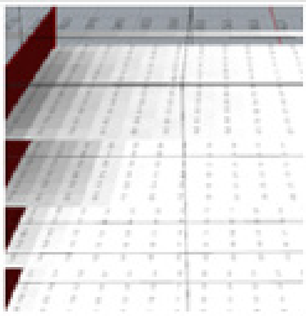
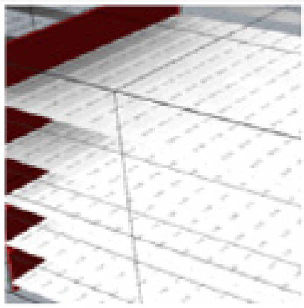
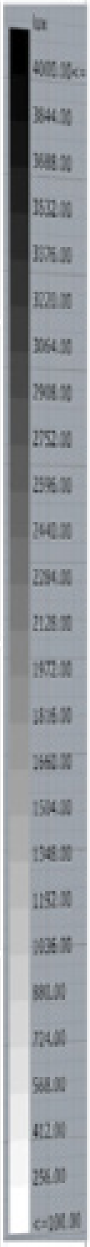
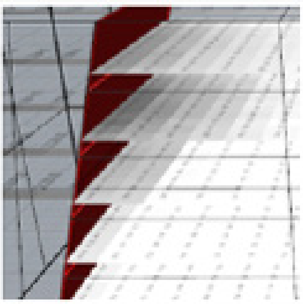
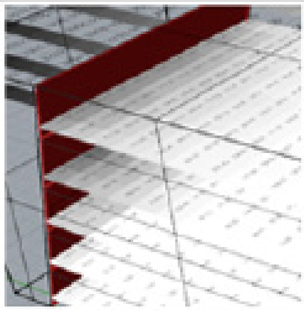
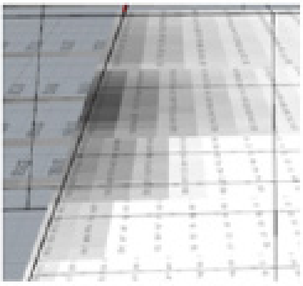
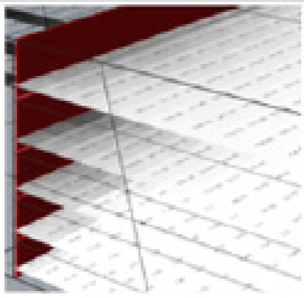
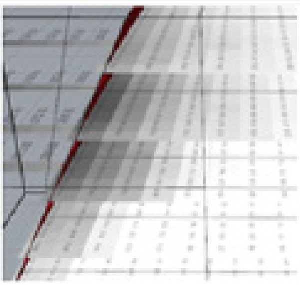
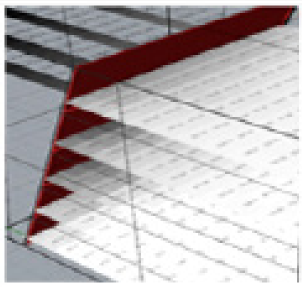
	Cases	Area Allocated to NOS (A)	Daylight Simulation with Honeybee		
Daylight Simulation for Winter Solstice (21st December)	2-m NOS width & 5-degree tilted wall	126.2 m²			
	2-m NOS width & 10-degree tilted wall	152.8 m²			
	2-m NOS width & 15-degree tilted wall	180.3 m²			
	2-m NOS width & 20-degree tilted wall	209.2 m²			

Table 6. Daylight Simulation with Honeybee for Vertical Wall for June 21st

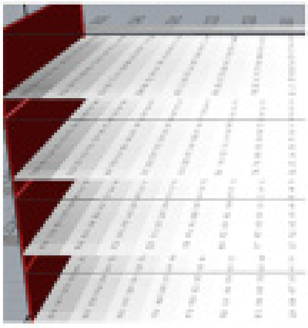
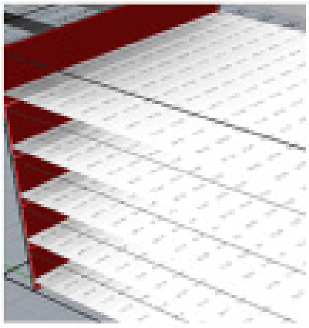
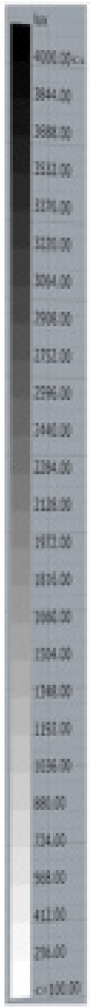
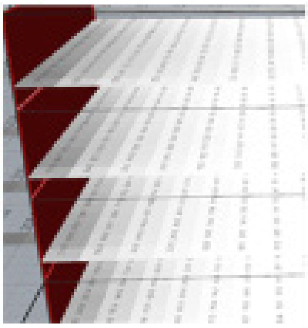
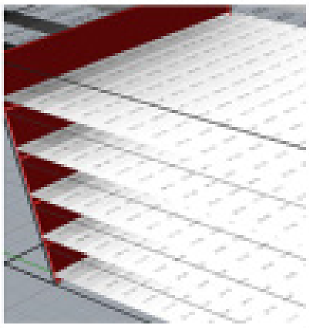
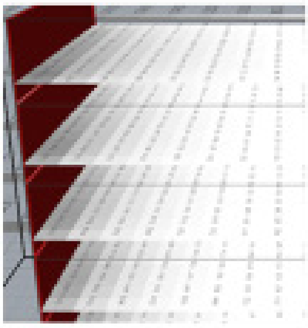
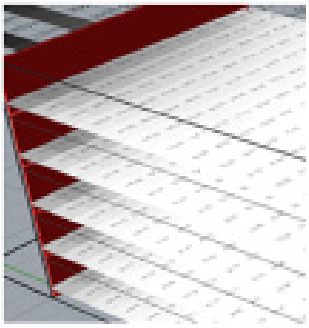
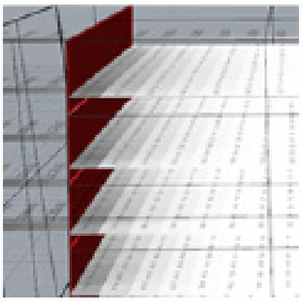
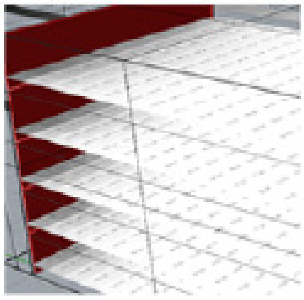
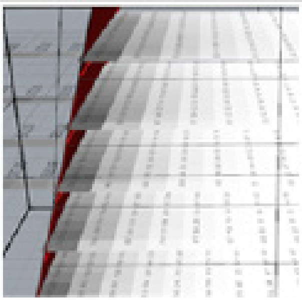
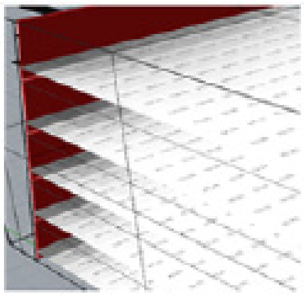
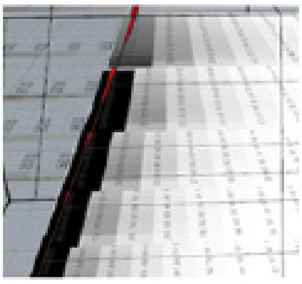
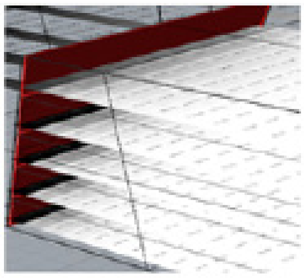
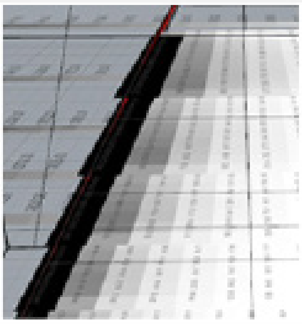
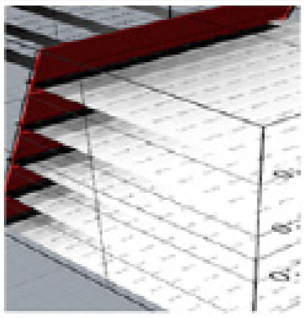
	Cases	Area Allocated to NOS (A)	Daylight Simulation with Honeybee		
Daylight Simulation for Summer Solstice (21st June)	2-m NOS width & vertical wall	100 m^2			
	3-m NOS width & vertical wall	150 m^2			
	4-m NOS width & vertical wall	200 m^2			

Table 7. Daylight Simulation with Honeybee for Tilted Wall for June 21st

	Cases	Area Allocated to NOS (A)	Daylight Simulation with Honeybee		
Daylight Simulation for Summer Solstice (21st June)	2-m NOS width & 5-degree tilted wall	126.2 m²			
	2-m NOS width & 10-degree tilted wall	152.8 m²			
	2-m NOS width & 15-degree tilted wall	180.3 m²			
	2-m NOS width & 20-degree tilted wall	209.2 m²			

RESULTS AND DISCUSSION

The following diagrams show the received Illuminance levels depending on the distance from the windows for each floor for any one of the cases. The sufficient illuminance levels are between two red lines. The top red line shows the glaring threshold (3000 lx) whereas the bottom red line shows the threshold of minimum standard illuminance level for the spaces (300 lx) (Fig. 4, 5, 6, and 7).

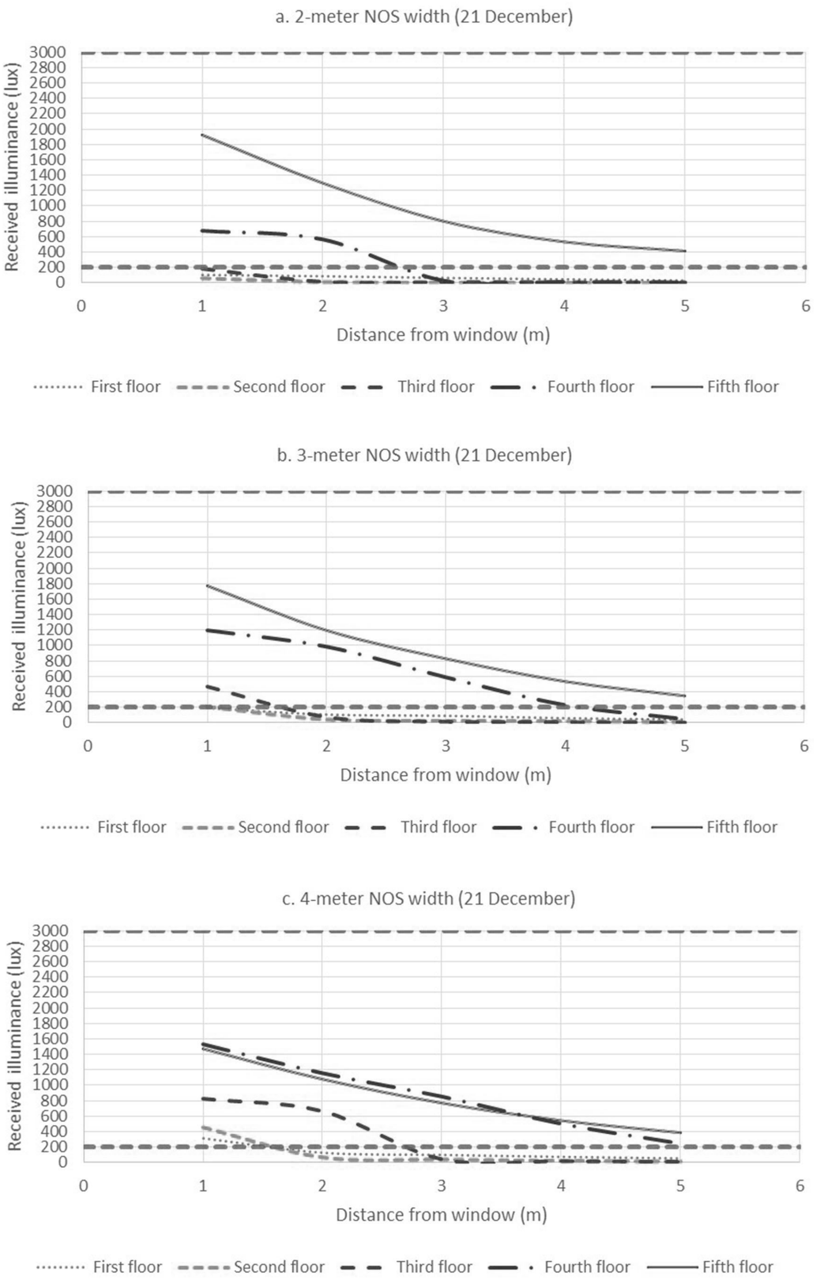


Fig. 4. Simulation Results for Vertical Wall for December 21st

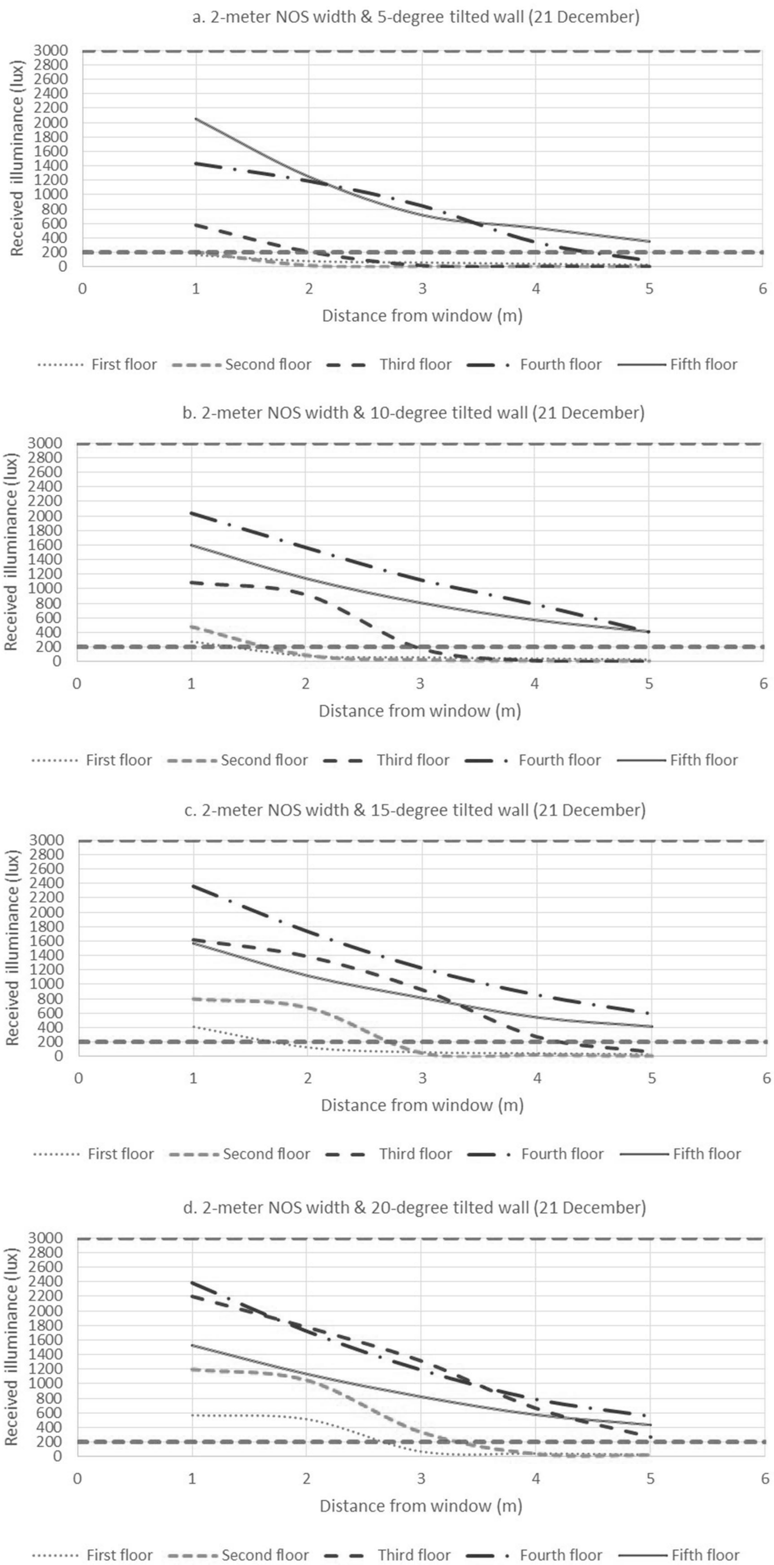


Fig. 5. Simulation Results for Tilted Wall for December 21st

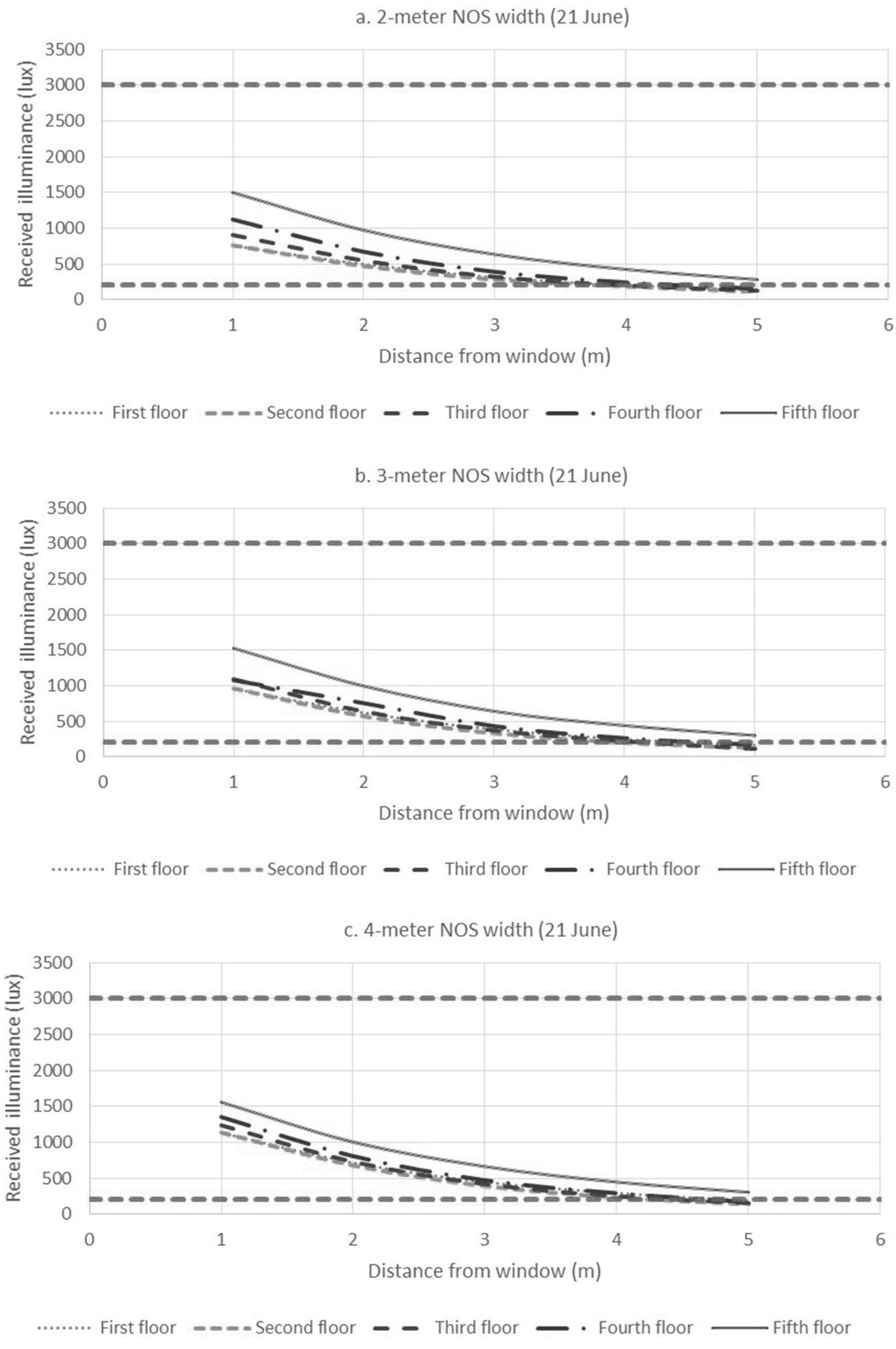


Fig. 6. Simulation Results for Vertical Wall for June 21st

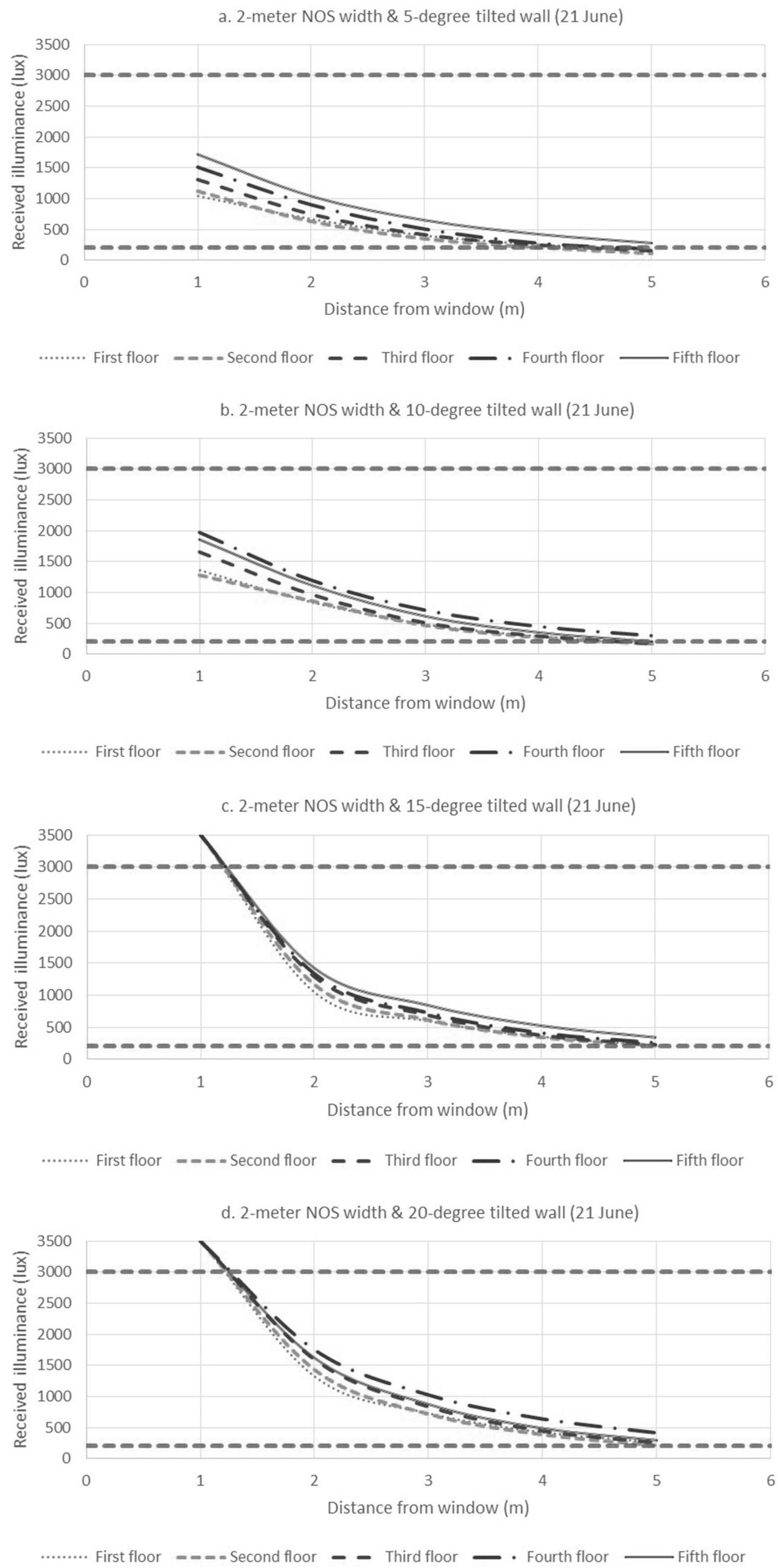


Fig. 7. Simulation Results for Tilted Wall for June 21st

The daylight simulations for the winter solstice were carried out to evaluate the illuminance level of the indoor spaces in the northern part of the building. Firstly, the simulation results for NOS with vertical walls reveals the following results:

In the first case with 2-m NOS width and 100 m^2 NOS area (Fig. 4 (a)) only the top floor receives sufficient daylight. The fourth floor has no suitable daylight between 2.5 to 5 meters distance from the window. The first, second, and third floors receive an illuminance level of less than 200 lx; therefore, a major part of the northern indoor spaces, even on the upper floors do not receive the standard daylight. Overall, this case has extremely undesirable results. Increasing the NOS width to 3 meters (150 m2 NOS area) (Fig. 4 (b)) slightly improves the daylighting condition on the fourth floor, but on the lower floors (first, second and third) still cannot provide the standard daylight for the indoor spaces. The most selected points in these floors show the illuminance level under 100 lx; therefore, it can be concluded that the 3-meter with NOS (the minimum value specified for the urban development standards) is not large enough to provide the standard lighting. The simulation results obtained for the third case with 4-meter NOS width and 200 m^2 area (Fig. 4 (c)) show that increasing NOS width from 3 m to 4 m provides a sufficient illuminance level for only the two upper floors and it cannot enhance it for the two lower floors. The third floor receives enough daylight only near the window; therefore, it does not make a significant change in the received daylight. Therefore, it can be concluded the in view of the size of the area dedicated to the NOS, the increase in width will not be viable.

Secondly the simulation results for NOS with tilted walls reveals the following results: The simulation results for the tilted wall with a 2-meter NOS width and 126.2 m^2 area (Fig. 5 (a)) show a noticeable change in the indoor daylight quantity. Using a 5-degree tilted wall in lieu of a vertical one improves the received daylight. In this case all, received illuminance level is similar to that case with 3 or even 4- meter width NOS with a vertical wall which are allocating more area to NOS. But very much like that one, the daylight is fails to provide the standard lighting for the two lower floors. The simulation results for the 10-degree tilted wall with a 2-meter width and 152.8 m^2 area (Fig. 5 (b)) has partially improves the daylighting condition. Here, the two upper floors and indoor spaces located 3 meters away from the third-floor window receive standard illuminance level, but the results for the two lower floors are not satisfactory. The results of this case can be compared with the third case with a 4-meter width and vertical wall; although, in this case, less area (152.8 m^2) is allocated to the NOS than the third one (200 m2). In the case with 15 degree tilted wall and 180.3 m^2 (Fig. 5 (c)) gradually improves the daylight simulation results. In the final case with a 20-degree tilted wall and 209.2 m^2 area there is a limited space on the lowest floor with undesirable illuminance level (Fig. 5(d)).

The daylight simulation for the summer solstice carried out to evaluate the illuminance level of the indoor spaces in the northern part of the building shows the following results:

The results of the simulations show that there was not a serious problem with glaring in such cases. In most of them, the illuminance level never exceeded 3000 lx (The glare threshold). The only exception visible is in the 15 and 20 tilted degrees in the indoor space with about a 1.5-meter distance from the window (Figs 6, 7).

CONCLUSION

The objective of this paper was to increase the daylighting efficiency of the NOS in residential apartments, pursued by daylight simulation of the NOS with different widths and for different tilts of its wall (located between NOS and indoor space). The results of simulations held on December 21st shows one-meter increase in NOS width (D) (from 2 to 3 m and from 3 to 4 m) while the increase is 10 m2 for the open space area. But it still failed to make significant improvement of daylight level for the spaces of lower floors in the illuminance level they received in winter. Therefore, it does not seem to be economically reasonable.

To test the research hypothesis, the daylighting of the NOS was simulated for 4 different wall angles; in these cases, the width (D) was assumed to minimum (2 meters) and the northern wall was assumed to have 5, 10, 15, and 20-degree tilts. The simulation results show that the impact of using a semi- funnel shape for NOS on the daylighting efficiency was much deeper than the effect of increasing the width of the NOS; meanwhile, semi funnel shape for NOS, relatively allocates less area to open space; therefore, economically is a better choice. In fact, the results produced by using a 5- degree tilted wall were similar to those produced by increasing the width (D) by 1 meter, even though the former approach would use less space and would be more economical. Increasing the degree of tilt from 5 to 10, from 10 to 15, and from 15 to 20 increases the received illuminance, such that at the 15-degree tilt all the floors receives the standard illuminance level at points on December 21st. To assess the possibility of visual discomfort due to the glare phenomenon, all the cases were also simulated for the summer solstice. The results of the simulations show that at no time did the illuminance exceed the glare threshold (3000 lx), the only exception being the upper indoor spaces with a 1-meter distance from the top floor window in the 15 and 20-degree tilted walls.

ENDNOTE

1. IRN_Esfahan.408000_ITMY.epw

REFERENCES

Arab, Y., & Hassan, A.S. (2012). Daylighting Analysis of Pedentive Domes Mosque Design during Summer Solstice with Case Studies in Istanbul, Turkey. International Transaction *Journal of Engineering, Management, and Applied Sciences and Technologies*, 3 (2), 167-183.

Du, J., & Sharples, S. (2010). Daylight in Atrium Buildings: Geometric Shape and Vertical Sky Components. *Lighting Research and Technology*, 42(4), 385-397.

Ghiabaklou, Z .(2013). *Fundamentals of Building Physics* 5. Tehran: Iran: University Jihad Organization Publications.

Hashemloo, AR., Inanici, M., & Meek, C. (2015). Glare Northern Shade: a Visual Comfort-based Approach to Occupant-centric Shading Systems. *Journal of Building Performance Simulation*, DOI: 10.1080/15502724.2015.1062392. http://www.isfahan.ir/

Ihm, P., Nemri, A., & Krarti, M. (2008). Estimation of Lighting Energy Savings from Daylighting. *Building and Environment*, 44, 509-514.

Krarti, M., Erickson, P.M., & Hillman, T.C. (2004). A Simplified Method to Estimate Energy Saving of Artificial Lighting Use from Daylighting. *Building and Environment*, 40(6), 747-754.

Lu, Y., Wolf, T., & Kang, J. (2016). Optimization of Facade Design Based on the Impact of Interior Obstructions to Daylighting. *Building Simulation*, 9, 1–14.

Nabil, A., & Mardaljevic, J. (2012). Useful Daylight Illuminance: A Replacement for Daylight Factors. Energy and Building, 38(7), 905-913.

Reinhart, C., Mardaljevic, J., & Rogers, Z. (2006). Dynamic Daylight Performance Metrics for Sustainable Building Design, *Leukos*, 3(1), 7-31.

Rezwan, S.M. (2015). Impact of Atrium Proportions on the Distribution of Daylight Level on the Adjacent Space in the Shopping Mall of Dhaka City. *International Journal of Science, Environment and Technology*, 4(3), 944-954.

Roudsari, M.S., Pak, M. (2013). Ladybug: *A Parametric Environmental Plugin for Grasshopper to Help Designers Create an Environmentally-conscious Design*. Proceedings of the 13th International IBPSA Conference, Lyon, August, 25-30.

Tahbaz, M. (2009). *Settlement Design Considering Natural Daylighting*. Light without Borders: 6th Lux Pacifica Int. Conf. Bangkok. Thailand.

Yun, G., Yoon, K.C., Kim, K.S. (2014). The Influence of Shading Control Strategies on the Visual Comfort and Energy Demand of Office Buildings of Shading Control Strategies on the Visual Comfort and Energy Demand of Office Buildings. *Energy and Building*, 84, 70-85.

Zawidzki, M. (2015). Dynamic Shading of a Building Envelope Based on Rotating Polarized Film System Controlled by One-dimensional Cellular Automata in Regular Tessellations (Triangular, Square and Hexagonal). *Advanced Engineering Informatics*, 29(1), 87-100.