Armanshahr Architecture & Urban Development, 10(18), 35-45, Spring 2017
ISSN: 2008-5079
EISSN: 2538-2365

The Analysis of Daylight Factor and Illumination in Iranian Traditional Architecture, Case Studies: Qajar Era Houses, Qazvin, Iran

Yousef Gorji Mahlabani[1*] and Aliasghar Mofrad Boushehri[2]

[1] Associate Professor of Architecture, Faculty of Architecture and Urbanism, Imam Khomeini International University, Qazvin, Iran.

[2] Master Student of Architecture, Faculty of Architecture and Urbanism, Imam Khomeini International University, Qazvin, Iran.

Received 30 July 2016; Revised 29 September 2016; Accepted 20 October 2016

ABSTRACT: As buildings are the biggest consumers of energy, reducing the total energy consumption in this area may have a significant role in preserving non-renewable resources. Appropriate use of daylight may decrease the need for electric lighting which may lead to reduced energy consumption and costs in lighting. Moreover, in the Iranian traditional architecture, there have been various passive strategies to take advantage of the renewable resources to provide thermal and visual comfort for users. Using daylight is one of these methods and strategies. The present study aims at analyzing the lighting condition of these buildings. Therefore, four buildings in Qazvin city, which belong to Qajar period (1785-7925 A.D.), were selected as the case studies. Then, the elected buildings were simulated as three-dimensional models. Finally, the analysis of daylight factor and illuminance was conducted using Ecotect Analysis, Energy Plus and VELUX Daylight Visualizer Software. After the analysis of data obtained from the respective simulations and their comparison with the extant standards of lighting, it was found that the average daylight factor at all under-scrutiny rooms was acceptable; in addition, 76 percent of rooms required no artificial light during the daytime. The reason for appropriate lighting in these spaces is positioning alongside the sunlit side of the building as well as use of big windows. In addition, the analysis of illuminance shows that the distribution of light in interior spaces is even. Moreover, although much amount of light enters the space, the use of light color prevents contrast and daze while enhances visual comfort.

Keywords: Iranian Traditional Architecture, Daylight Simulation Software, Illuminance, Daylight Factor.

INTRODUCTION

The issue of climate change is one of the greatest challenges humanity faces today. In recent decades, increased GHG emissions have been an influencing factor in the occurrence of the aforementioned phenomenon. Reduced use of non-renewable and fossil fuels as well as increased energy efficiency may reduce such emissions. A main share of total energy consumption is dedicated to the construction sector. Reduced energy consumption in this sector may have an effective role in preserving limited resources. For instance, 40% of total energy in U.S. is consumed in buildings (URL1, 2016). This energy is used for heating, cooling, hot water supply and electricity. The electricity used for artificial lighting accounts for approximately 14% and 19% of total electricity consumption in buildings in, respectively, EU and the world as a whole (Gago et al., 2015). Using natural light in design process may also reduce electricity consumption for artificial lighting over 50-80%, and consequently lead to saving in buildings electricity consumption as well (Bodart & De Herde, 2002; Mardaljevic et al., 2009). In addition to methods of reducing energy and electricity consumption in buildings, using natural light may also result in increased visual comfort and productivity for users (Leslie, 2003; Oral et al., 2004). Moreover, while the luminous efficiency (i.e. the ratio of luminous flux to power) is between 90-120 lumens per watt (depending

* Corresponding Author Email: gorji@arc.ikiu.ac.ir

on sky conditions), the aforementioned value in incandescent lamps and LED lamps is only 10-15 and 75-90 lumens per watt, respectively. Using natural light not only may reduce energy consumption in lighting area, but also produce less heat compared to artificial lighting, and reduce cooling load on a building (Canziani et al., 2004; Li & Lam, 2001; Sayigh, 2014; Xu & Yuehong, 2015). Therefore, appropriate architectural design by using natural light may have a significant role in reducing total energy consumption in buildings and consequently may turn the latter to an energy-efficient building (Li & Tsang, 2008).

Many elements such as local climate, building orientation, ratio of window to wall, window size, and the placing of adjacent buildings influence the amount of light received by the interior (Dubois & Flodberg, 2012; Krüger & Dorigo, 2008; Lee et al., 2013; Ran et al., 2009).

In Iranian traditional architecture, manifold strategies have been provided to use renewable energy resources, some of which could be used in this era as well. Using natural light is one of these strategies. In this type of architecture, the attempt has been continuously made to design orientations, dimensions and proportions of the openings in main internal spaces in a way that the space is well lighted during daytime. The present study aims to estimate the amount of daylight and illuminance in main spaces (living rooms and bedrooms) in 4 residential buildings belonging to the Qajar period (1785-1925 A.D.) by using computerized simulations. Then, the lighting condition of the studied buildings is tackled by comparing the obtained values with the international standards of daylight.

LITERATURE REVIEW

In relation to Iranian traditional architecture, several studies have been carried out on climate-related solutions. In some studies, Iranian buildings located in hot and arid climates were investigated. In these buildings, the thermal comfort of residents has been met by using natural as well as renewable energy resources. Some other studied methods include wind catcher, dome and vault, basement (Crypts), Loggia (Talar or Eyvan), Deep enclosed yards and Openings shelter (Eirajia & Akbari Namdar, 2011; Foruzanmehr, 2015; Khalili & Amindeldar, 2014; Saljoughinejad & Rashidi Sharifabad, 2015). In addition, several researches on the central yard have also been carried out, in which the function of yards as micro-climate, their orientation, proportions and dimensions and even their role in providing passive cooling to improve thermal comfort of residents have been addressed (Soflaei et al., 2015; Soflaei et al., 2016).

In respect to daylight condition in Iranian traditional architecture, there are also several studies. In one of these, the types of components in providing natural lighting in Iranian traditional buildings were examined. Additionally, there are some studies in terms of the level of lighting in different parts of buildings in Kerman and Kashan cities (Tahbaz & Kazemzadeh, 2013; Tahbaz & Moosavi, 2009; Tahbaz et al., 2014). According to the fact that Iranian traditional architecture in its different cities has been shaped proportional to the specific climate as well as cultural conditions of that region, the features and principles used in the architecture of each of these zones are required to be individually scrutinized. From this perspective, no research found on daylight condition in traditional architecture of Qazvin city. Hence, in this study, the attempt is made to investigate the illuminance and daylight factor in 4 historical buildings in Qazvin city.

THE OVERALL SPECIFICATIONS OF THE CASE STUDIES

Qazvin city is located in the Northwest of Iran in the latitude of about 36.27 °N and the longitude of 5000 °E. To analyze the means of taking advantage of daylight in traditional houses, 4 residential buildings belonging to the Qajar period were selected. All 4 buildings were located in the same district in Qazvin city. All the selected buildings had a yard, and main spaces such as living rooms and bedrooms surrounding the yard, and therefore easily received daylight.

The studied buildings include Behruzi, Yazdi, Imamjom’e, and Beheshti houses. For the ease of comparison, the aforementioned buildings were named A to D, respectively. The studied rooms were also numbered (Figs. 3 and 4) as well. The under-scrutiny rooms include living rooms (5-door and 7-door rooms) and bedrooms (3-door rooms) which are considered to be the major spaces in Iranian traditional houses, that is to say, the spaces where residents mostly spend their time.

A: Behruzi house

B: Yazdi house

C: Imam jom'e house

D: Beheshti house

Fig. 1. The Studied Historical Buildings in Qazvin

SAMPLE MODELING PROCESS

Regarding the fact that merely the buildings plans were available, field surveys and photography were used to recognize the buildings' volumes. Additionally, since buildings underwent changes during the last years, some old pictures were also used to allow modeling of the buildings' original volumes. Moreover, in field surveys, the used materials in floors, walls, ceilings and exterior facades also recorded to be use in the simulations of daylight and illuminance.

As the studied buildings had undergone some changes, using simulations software appeared to be the best way to achieve more precise information about the buildings performance in terms of receiving daylight. Therefore, first 3D models of all the samples were produced in building modeling software. In this process, it was tried to model adjacent spaces, basements and neighborhood units coupled with main spaces supposed to be analyzed to provide more precise results in the succeeding steps. Moreover, the type of materials was chosen in accordance to the original materials (e.g. bricks for exterior walls, plaster for interior walls, wood for doors and windows frames and single-layered glass for glazing) used in the buildings.

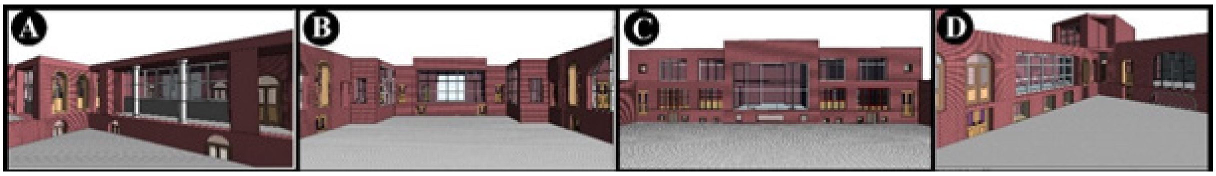

Fig. 2. Shaded Images of 3D Modeled Houses

Then, the aforementioned 3D models had to be entered into the lighting and energy simulation software to analyze daylight. In this regard, an export with gbxml format was prepared to be entered into Ecotect Analysis and Energy Plus programs. In this process, the main spaces were analyzed in terms of daylight and illuminance were determined as "Rooms" and subsequently numbered. In addition, an export with DWG format was prepared to be used in VELUX Daylight Visualizer program.

DAYLIGHT ANALYSIS BY ECOTECT SOFTWARE

Ecotect Analysis software is a tool with the potential of using in modeling different volumes. It is able to conduct analyses in terms of energy, sunlight radiation, lighting, shading, thermal load, acoustics and different costs for either a specific building or a series of buildings. Indeed, this software may help architects evaluate the performance of buildings at the very beginning steps of buildings design process (Wu & Gao, 2016). The results of a survey in 2009 indicated that among architects who responded the given questionnaire, over 64% of architects use Ecotect Analysis software to simulate the performance of the building. According to this survey, this software is mostly used at the early stages of concept and project design (Attia et al., 2009).

In this study, the data file related to the modeled volumes was firstly entered into the software. Afterwards, to recognize the location of site and the direction of sunlight radiation in Qazvin city, the weather file of this city was imported into the software. Each room was individually analyzed to measure the average daylight factor. Accordingly, 21 analyses were performed to analyze the performance of buildings in natural light use. Moreover, the minimum and maximum values of daylight factor in each room were determined. CIE Overcast Sky was the sky model used in this analysis, and 0.75 was the height regulated for analysis grid from the floor. Single-glazed timber frame with visible transmittance of 0.78 was used for windows. Although, in real condition, the windows in selected samples were not well clean, window cleanliness was considered to be equaled 1 to finally allow the light transmission coefficient to be computed as 0.78 and enable the comparison of yielded analyses with the analyses of other software. In internal surfaces, plaster walls with the reflection coefficient of 0.68 were used.

Finally, all the analyses were overlaid on the buildings 2D maps. Fig. 3 indicates the position of rooms in the buildings as well as their orientation, so the comparison of daylight in different spaces may be possible.

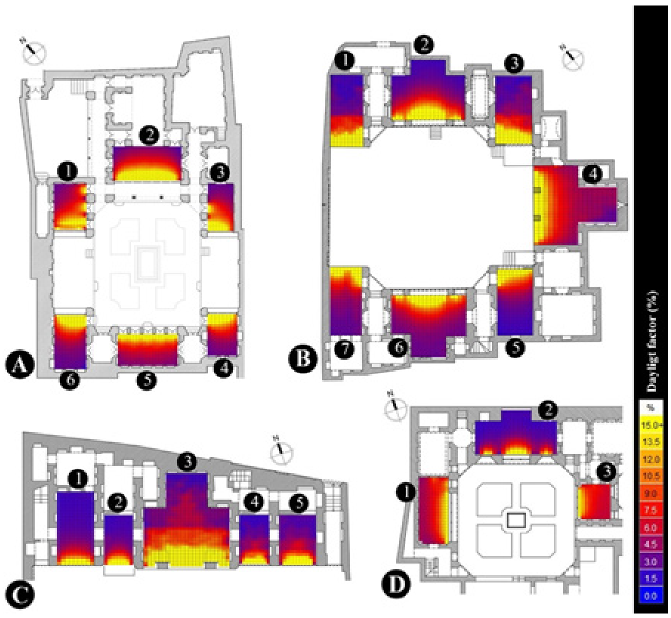

Fig. 3. Ecotect Simulation of Daylight Factor (Which Overlaid on CAD Plans). First Floors of Behruzi House (A), Yazdi House (B), Imam jom'e House (C) and Beheshti House (D) Including Rooms Numbers.

Daylight Analysis by Energy Plus Software

Energy Plus is a widely used software for the building energy simulation presented by the United States Department of Energy (DOE) (Witte et al., 2001). This software has the strengths of both BLAST and DOE-2 programs. Some of its strengths include as follows: Heat balance calculation, Interior surface convection, Thermal comfort, Moisture absorption/desorption, Anisotropic sky model, Advanced fenestration calculations and Daylighting illumination and controls (Crawley et al., 2001). To analyze daylight, Energy Plus measures the reflections of both interior surfaces and adjacent buildings with an advanced method (Li & Wong, 2007). Moreover, the computational accuracy of the software has been proved (Witte et al., 2001).

In this software, climate data file of Qazvin (with epw format) was used to measure the sun positioning and its zenith and azimuth angle in accordance to the climatic characteristics of the city. Like the previous analysis in Ecotect, in this analysis, light transmission of 0.78 was used for the windows. Reflection coefficient for ceilings, roofs, and walls materials was considered to be 0.68. Working plane height was regulated as 0.75 m, and CIE overcast sky was used as the sky model in this analysis. Then, the analyses for each of the zones were individually performed. Generally, 21 analyses were conducted in this software. The results were obtained in two map and grid formats (Fig. 4). Map-format images as the graphical display of analysis were overlaid on the buildings maps. Results presented in grid format include floor area, average daylight factor, minimum daylight factor, maximum daylight factor and floor area above threshold. This data was used in the following to provide more precise analyses of the daylight factor in different spaces (Table 1).

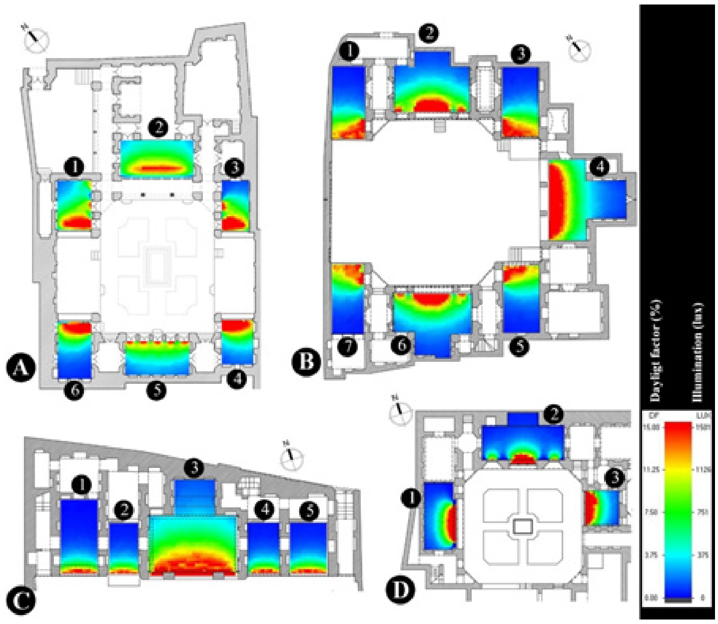

Fig. 4. Energy Plus Simulation of Daylight Factor and Illumination (Which Overlaid on CAD Plans). First Floors of Behruzi House (A), Yazdi House (B), Imam jom'e House (C) and Beheshti House (D) Including Rooms Numbers.

Daylight and Illuminance Analysis by VELUX Daylight Visualizer

VELUX Daylight Visualizer is used to display spaces lighted by the natural light and to estimate the amount of daylight as well. This software simulates transmittance of daylight in different spaces of the building; moreover, it helps architects to observe the level of daylight and its distribution in different spaces of the building at the very beginning steps of design process (Labayrade et al., 2009). This software may allow the simulation of daylight under 16 different sky models designed according to the standard sky models. Computational accuracy of the software was confirmed in CIE TC 3-33 "Test Cases to Assess the Accuracy of Lighting Computer Programs". This test, indeed, may allow the users of Light analyzer computerized programs to learn the accuracy rate of programs used in the analysis (URL2, 2016).

To analyze the selected samples, first 3D models were imported into the software and then the coordinates of Qazvin (latitude 36.27o N and longitude 50.00o E) as well as building orientation were determined. Overcast sky was selected as the Sky model from among 16 sky models presented by Daylight Visualizer. In this analysis also, light transmission of 0.78 was used for the windows to allow the estimation of daylight shining over the inner spaces of the building. As in the interior surfaces, walls and ceilings are made of plaster with white color and floors are covered with light-colored bricks, reflection coefficient for walls, ceilings, and floors was considered 0.68. In these surfaces, the roughness and specularity were, respectively, 0.03 and 0.

As the windows frameworks were made of wood in the studied samples, in order to increased accuracy, the material used in the simulation in Daylight Visualizer software for these surfaces was considered to be wood with reflection, roughness, and specularity of 0.664, 0.02, and 0.05, respectively. To measure the daylight factor value in different buildings, Plan View that was considered at height of 0.75 to be equal with previous analyzes, was applied.

To compute the illuminance in some rooms, view mode was chosen to be perspective and camera height was considered to be 1.70 m. Calculations were done on Mars 21st (vernal equinox) at 12:00 A.M. Like daylight factor analysis, in this analysis overcast sky was chosen to calculate the minimum natural light received in interior spaces in this date. Naturally, in sunny sky and intermediate sky conditions, inner spaces may receive the highest natural light. The results of these analyses ultimately presented as false color and ISO contours images including grid values (Figs. 5-8). In fact, illuminance is representative of the light distribution and its intensity in different parts of the room. Accordingly, luminance computation also performed for the studied rooms and similar arrangements applied on illuminance analysis, was also used in this case (Figs. 5-8).

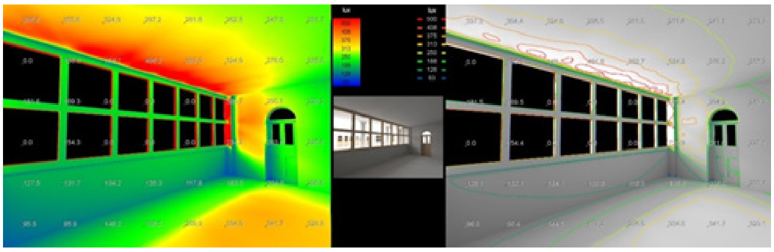

Fig. 5. Illuminance Image (False Colour and ISO Contours) and Luminance Image of Main Living Room of Behruzi House (A2).

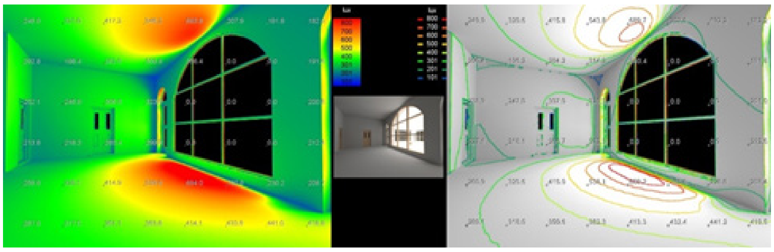

Fig. 6. Illuminance Image (False Colour and ISO Contours) and Luminance Image of Living Room of Yazdi House (B4).

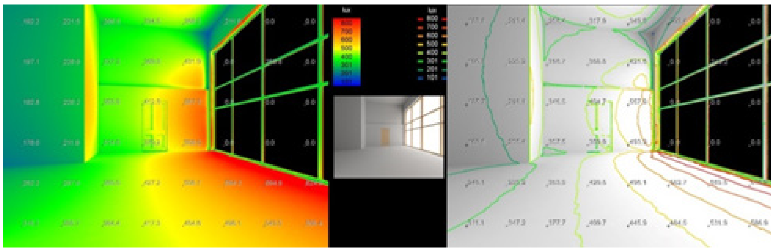

Fig. 7. Illuminance Image (False Colour and ISO Contours) and Luminance Image of Main Living Room of Imam jom'e House (C3).

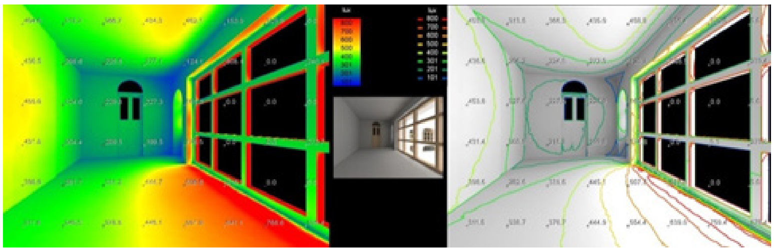

Fig. 8. Illuminance Image (False Colour and ISO Contours) and Luminance Image of Main Living Room of Beheshti House (D1).

In cases which daylight is used for the lighting of spaces, the even distribution of light is especially important and the consideration of natural sunlight in the early stages of design with the aim of controlling sharp sunlight and allowing other even lights to pass is necessary. Research conducted by the National Research Council Canada shows that generally in spaces with illuminance higher than 150 lux, the amount of light infiltration is acceptable (Alrubaih et al., 2013). As shown in Figs. 5-8 almost in all parts of the room, the amount of illuminance is higher than 150 lux. Also, with the use of big windows in all the wall, the distribution is almost even which has resulted in the visual comfort of the user.

RESULTS AND DISCUSSION

Living rooms and bedrooms where residents mostly spend their time were considered the main spaces of the buildings to analyze the lighting condition of the under-scrutiny buildings. After modeling the studied buildings, daylight simulation was conducted by three software, namely Ecotect Analysis, Energy Plus, and VELUX Daylight Visualizer. Then, the obtained data was collected in a table (Table 1). This table presents information about the average daylight factor, minimum daylight factor, and maximum daylight factor in each room. As a result, a mean of average, minimum, and maximum daylight factor values computed by three above mentioned software was obtained to achieve more precise results and reduce possible errors as well.

The values obtained from the analyses are required to compare to standard values in order to assess the performance of buildings in daylight use. The performance of these buildings could be concluded acceptable provided that the results obtained in this study concord the standard values. Because there are standard values for neither the average daylight factor nor minimum acceptable daylight factor for different spaces in Iran, standards of other regions were used instead. In British standard (BSI, 2008), criteria have been determined for daylight condition of the different spaces of the residential buildings. When these criteria are met, it simply means that there is appropriate daylight in rooms. On this ground, the minimum average of daylight factor value for kitchen, living room, and bedroom has to be, respectively, 2%, 1.5%, and 1%. Moreover, the design has to be in a way to provide direct daylight for the considerable part of the room (Littlefair, 2001).

Table 1. Minimum, Average and Maximum Values of DF (Daylight Factors) for Each Room Calculate by VELUX Daylight Visualizer, Ecotect Analysis and Energy Plus and Average of These Three Software's Calculations. in the Last Column, Percentage of Room Area in which Daylight Factor is Above 2%.

House name	Room number	Room function	VELUX Daylight Visualizer			Ecotect Analysis			Energy Plus			Average of three Software's Analysis			
			Min. DF (%)	Av. DF (%)	Max. DF (%)	Min. DF (%)	Av. DF (%)	Max. DF (%)	Min. DF (%)	Av. DF (%)	Max. DF (%)	Min. DF (%)	Av. DF (%)	Max. DF (%)	Area above 2% (%)
Behruzi House (A)	1	Bedroom	2.12	7.69	18.37	3.11	8.83	16.19	1.48	8.08	20.55	2.23	8.20	18.37	100
	2	Living	2.11	5.61	8.54	2.53	8.95	22.96	1.35	6.76	15.25	2.00	7.10	15.58	100
	3	Bedroom	1.91	7.26	18.64	2.95	7.83	18.89	1.75	7.76	23.49	2.20	7.62	20.34	100
	4	Bedroom	1.82	5.62	11.20	2.77	8.05	22.03	1.09	7.68	24.96	1.89	7.12	19.40	95
	5	Bedroom	1.73	5.14	8.30	3.26	7.34	20.08	1.32	5.68	15.89	2.10	6.05	14.76	100
	6	Bedroom	1.83	6.18	19.60	2.03	8.21	20.70	0.54	6.56	20.34	1.47	6.98	20.21	90
Yazdi House (B)	1	Bedroom	1.06	6.12	14.00	1.66	7.56	23.80	1.21	4.65	20.89	1.31	6.11	19.56	80
	2	Living	1.31	5.90	19.64	1.74	7.10	22.08	1.57	5.45	23.35	1.54	6.15	21.69	90
	3	Bedroom	1.06	6.79	22.15	1.21	7.42	24.48	0.89	4.98	20.55	1.05	6.40	22.39	80
	4	Living	1.41	8.53	26.82	2.46	8.55	19.28	1.56	7.85	23.96	1.81	8.31	23.35	95
	5	Bedroom	1.22	5.27	18.39	1.65	5.96	18.00	0.94	4.83	21.17	1.27	5.35	19.19	80
	6	Living	1.45	5.47	14.19	2.97	6.86	22.58	1.63	5.64	22.74	2.02	5.99	19.84	100
	7	Bedroom	1.15	5.94	13.11	2.58	6.81	19.66	1.317	4.87	19.14	1.68	5.87	17.30	85
Imam Jom'e House (C)	1	Bedroom	0.43	3.27	16.06	1.68	4.48	23.56	0.86	2.42	18.76	0.99	3.39	19.46	50
	2	Bedroom	0.65	4.33	8.10	1.61	5.38	22.98	0.77	3.24	19.07	1.01	4.32	16.72	85
	3	Living	2.21	8.91	25.97	1.65	8.74	24.88	0.93	7.57	22.53	1.60	8.41	24.46	95
	4	Bedroom	1.15	3.71	8.38	1.70	5.48	26.40	1.27	3.115	19.02	1.37	4.10	17.93	85
	5	Bedroom	1.14	3.91	16.58	1.92	6.49	25.95	1.33	3.39	19.21	1.46	4.60	20.58	90
Beheshti House (D)	1	Living	1.59	5.65	12.17	1.85	7.50	23.35	1.35	5.23	22.99	1.60	6.13	19.50	90
	2	Bedroom	1.06	3.26	11.41	1.57	4.14	18.63	0.96	3.09	23.15	1.20	3.50	17.73	75
	3	Bedroom	1.92	7.56	21.78	1.62	8.11	18.30	0.92	7.95	28.85	1.49	7.87	22.98	95

Generally, according to IES standard (IESNA RP-5-99), when the average daylight factor for the interior space is less than 2%, it simply means that the space lighting is low. On the contrary, if the average daylight factor is 5% or more, it necessarily means that the space is well lighted. Furthermore, according to British standard (BS 8206 part2, 2008), if a place may frequently use no electric lighting during the daytime, the average daylight factor should not be less than 5%. If electric lighting is used during the day, the average daylight factor should not be less than 2% (Iommi, 2016). In order to compare the values obtained for daylight factor in different rooms with the values mentioned in the aforementioned standards, a chart is provided (Fig. 9).

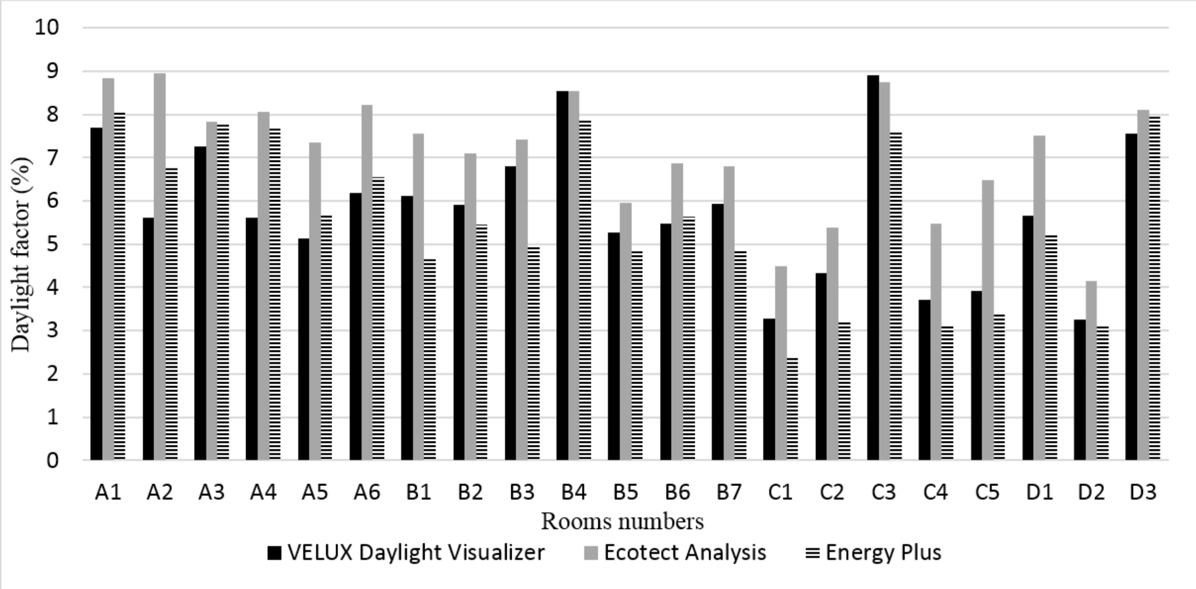

Diagram 1. Comparison of Average Daylight Factor in Different Rooms

As seen in Fig. 9, based on the results of VELUX Daylight Visualizer, the medium light factor in 16 rooms was above 5 percent which indicates that 76 percent of rooms don't need electrical lighting. The light factor figures from Ecotect Analysis shows that 19 rooms have a light factor of above 5 percent and therefore 90 percent of rooms don't need artificial lighting and only two rooms C_1 and D_2 (with medium light factor of 4.48 and 4.14) require artificial lighting in some times of the day for visual comfort. Although the results of Energy Plus simulation are lower than the two other simulations, but based on these numbers more than half of the rooms have a light factor of above 5 percent. If we consider the median of the results of the three software, it can be concluded that 76 percent of the analyzed rooms don't require electrical light for visual comfort.

The important thing is that in all simulations adopted in the three software, the amount of median light factor in all rooms was above 2 percent. In addition, all rooms with average daylight factor of less than 5%, were bedrooms. According to the above mentioned standards, bedrooms require less average daylight factor compared to living rooms. In all 4 studied historical buildings, at least in 90% of living room areas, the daylight factor was more than 2%, representing in designing these buildings, the received natural light in living rooms had been more significant compared to other spaces of the building.

Generally, in analyses carried out in whole spaces of the buildings, it was found that rooms located at the back of the main spaces or basements receive less daylight than the main spaces. These spaces include warehouses, food storage rooms, and in some cases, domestic cisterns which have no opening or their opening surface failed to be adequate. However, these spaces fitted the needs of last generation and in modern architecture, some of them are no longer required.

In short, it can be concluded that in these buildings, the level of daylight use for rooms was highly dependent to the importance of the space. For instance, in spaces like living rooms and bedrooms where residents mostly spend their time, daylight factor and illuminance values were consistent even with the international standards of this era regarding daylight. However, spaces rarely used were located at the back of main spaces or basements and their lightness had been less important.

CONCLUSIONS

In the present study, 4 Iranian historical buildings were modeled using different software and their lighting condition was analyzed. The results obtained from the simulations revealed that the average daylight factor in all under-scrutiny rooms was at an acceptable level (more than 2%), hence these rooms were well lighted by the natural lighting. Moreover, the comparison of data from these analyses with the international standards of lighting may shed some light on the fact that 76% of the studied rooms do not require artificial lighting during daytime (with average daylight factor more than 5%). A crucial point that should be mentioned is that all living rooms were in good condition and received good daylight. Likewise, all bedrooms received natural light more than the acceptable value mentioned in these standards. However, a point that should be clarified here is that, more than half of bedrooms (60%) do not require electric lighting during daytime. Lack of need for such artificial lighting may lead to reduced total energy consumption in the building.

Also, the analysis of illuminance and luminance distribution in Living rooms shows that daylight infiltration is sufficient and its balanced distribution enhances visual comfort. The architectural solution that has led to this is the use of windows in spaces receiving more light, especially in Living rooms.

Therefore, it is recommended to use one horizontal and continues opening instead of a number of small openings in main spaces in order to prevent uneven daylight distribution and sunlight contrast which result in daze; In this case, using gridded windows like traditional window works is suggested. Depending on its grid density, the amount of light and window surface can be controlled. As pointed out in the sample studies, using light-colored material with higher reflection coefficient in interior spaces, can increase the overall room light and reduce the contrast between the light and interior walls which increases the visual comfort of users.

REFERENCES

Alrubaih, M.F.M., Alghoul, N.L.N., Shameri, M.A., & Elayeb, O. (2013). Research and Development on Aspects of Daylighting Fundamentals, Renew. *Sustain Energy Rev*, 21, 494–505.

Attia, S., Beltrán, L., De Herde, A., & Hensen, J. (2009). Architect Friendly: A Comparison of Ten Different Building Performance Tools, *Building Simulation in Proceedings of Eleventh International IBPSA Conference*.

Bodart, M., & De Herde, A. (2002). Global Energy Savings in Offices Buildings by the Use of Daylighting. *Energy and Buildings*, 34(5), 421-429.

BSI (2008). *Lighting for Buildings - Part 2: Code of Practice for Daylighting*, British Standards Institution, London.

Canziani, R., Peron, F., & Rossi, G. (2004). Daylight and Energy Performances of a New Type of Light Pipe. *Energy Build*, 36(11),1163–1176.

Crawley, D.B., Lawrie, L.K., Winkelmann, F.C., Buhl, W.F., Huang, Y.J., Pedersen, C.O., Strand, R.K., Liesen, R.J., Fisher, D.E., Witte, M.J., & Glazer, J. (2001). EnergyPlus: Creating a New Generation Building-Energy Simulation Program. *Energy Build*, 33(4), 319–31.

Dubois M.C., & Flodberg K. (2012). Daylight Utilisation in Perimeter Office Rooms at High Latitudes: Investigation by Computer Simulation, *Light Res Technol*, 45, 52–75.

Eirajia, J., & Akbari Namdar, S. (2011). Sustainable Systems in Iranian Traditional Architecture, *2011 International Conference on Green Buildings and Sustainable Cities, Procedia Engineering*, 21, 553-559.

Foruzanmehr, A. (2015). People's Perception of the Loggia: A Vernacular Passive Cooling System in Iranian Architecture, *Sustainable Cities and Society*, 19, 61-67.

Gago, E.J., Muneer, T., Knez, M., & Köster, H. (2015). Natural Light Controls and Guides in Buildings. Energy Saving for Electrical Lighting, Reduction of Cooling Load, *Renewable and Sustainable Energy Reviews*, 41, 1-13.

Iommi, Matteo. (2016). The Natural Light in the Italian Rationalist Architecture of Ex G.I.L. of Mario Ridolfi in Macerata. The Virtual Reconstruction and the Daylight Analysis of the Original Building, *Energy and Buildings*, 113, 30-38

Khalili, M., & Amindeldar, S. (2014). Traditional Solutions in Low Energy Buildings of Hot-Arid Regions of Iran, *Sustainable Cities and Society*, 13, 171-181.

Krüger, E.L., & Dorigo, A.L. (2008), Daylighting Analysis in a Public School in Curitiba, Brazil, *Renew Energy*, 33, 1695-702.

Labayrade, R., Jensen, H.W., & Jensen, C. (2009). Validation of Velux Daylight Visualizer 2.0 Against CIE, *Building Simulation 2009 IBPSA Conference*, 171.

Lee, J.W., Jung, H.J., Park, J.Y., Lee, J.B., & Yoon, Y. (2013). Optimization of Building Window System in Asian Regions by Analyzing Solar Heat Gain and Daylighting Elements, *Renew Energy*, 50, 522-531.

Leslie, R.P. (2003). Capturing the Daylight Dividend in Buildings: Why and How?, *Building and Environment*, 38, 381-385

Li, D.H.W., & Lam, J.C. (2001). Evaluation of Lighting Performance in Office Buildings with Daylighting Controls, *Energy and Buildings*, 33, 793-803.

Li, D.H.W., & Tsang, E.K.W. (2008). An Analysis of Daylighting Performance for Office Buildings in Hong Kong, *Building and Environment*, 43(9), 1446-58.

Li, D.H.W., & Wong, S.L. (2007). Daylighting and Energy Implications due to Shading Effects from Nearby Buildings, *Applied Energy*, 84, 1199-1209.

Littlefair, P. (2001). Daylight, Sunlight and Solar Gain the Urban Environment, *Solar Energy*, 70, 177-185

Mardaljevic, J., Heschong, L., & Lee, E. (2009). Daylight Metrics and Energy Savings, *Lighting Research Technology*, 41(3), 261-283.

Oral, G.K., Yener, A.K., & Bayazit, N.T. (2004). Building Envelope Design with the Objective to Ensure Thermal, Visual and Acoustic Comfort Conditions, *Build. Environ*, 3, 281-287.

Ran, Y., Li, S., Su, Y., & Riffat, S. (2009), Daylighting Performance of Atriums in Subtropical Climate, *Int J Low-Carbon Technol*, 4, 230-237.

Saljoughinejad, S., & Rashidi Sharifabad, S. (2015). Classification of Climatic Strategies, used in Iranian Vernacular Residences based on Spatial Constituent Elements, *Building and Environment*, 92, 475-493.

Sayigh, A. (2014). *Sustainability, Energy and Architecture, Case Studies in Realizing Green Buildings*, Cambridge: Academic Press.

Soflaei, F., Shokouhian, M., & Mofidi Shemirani, S.M. (2015). Investigation of Iranian Traditional Courtyard as Passive Cooling Strategy (A Field Study on BS Climate), *International Journal of Sustainable Built Environment*, 5, 99-113.

Soflaei, F., Shokouhian, M., & Mofidi Shemirani, S.M. (2016). Traditional Iranian Courtyards as Microclimate

Modifiers by Considering Orientation, Dimensions, and Proportions, *Frontiers of Architectural Research*, 5, 225-238

Tahbaz, M., & kazemzadeh, M. (2013). Measurement and Analyzing Daylight Condition in Traditional Kerman Houses (Aminian house), *Honarihaye Ziba*, 18(2), 17-26.

Tahbaz, M., & Moosavi, F. (2009). Daylighting Methods in Iranian Traditional Architecture (Green Lighting), *International Conference, EPFL Lausanne, Switzerland*, 273-278.

Tahbaz, M., Jalilian, S., Moosavi, F., & kazemzadeh, M. (2014). Natural Daylighting in Traditional Houses in Kashan, Case Study of Ameri House, *Iranian Architecture Studies*, 4, 87-108.

URL1: http://www.eia.gov/tools/faqs/faq.cfm?id=86&t=1. (Visited on 3 September 2016).

URL2: http://www.cie.co.at/index.php/index.php?i_ca_id=447. (Visited on 14 August 2016).

Witte, M.J., Henninger, R.H., Glazer, J., & Crawley, D.B., (2001). Testing and Validation of a New Building-Energy Simulation Program. *Proceedings of Building Simulation 2001, Rio de Janeiro, Brazil: IBPSA*, 353-60.

Wu, Q., & Gao, W. (2016). Research on the Design of Ecological Energy-Saving Building based on the Climate Condition of Hangzhou, Procedia - *Social and Behavioral Sciences*, 216, 986-997.

Xu, Y., & Yuehong, S. (2015). Daylight Availability Assessment and its Potential Energy Saving Estimation, A Literature Review, *Renewable and Sustainable Energy Reviews*, 52, 494-503.