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Analysis of Lighting Performance between Single Dome and Pyramid Roof Mosque in Mostar, Bosnia Herzegovina

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Abstract

This study analyses a level of lighting performance between pedentive dome and pyramid roof mosque's construction in Mostars, Bosnia Herzegovina. The selected case studies are Karadjoz Beg (pedentive dome) and Neziraga Mosque (pyramid roof) which are located less than 500 metres apart from each other. The purpose is to assess information on the architectural roof design in relation to lighting performance. This assessment is simulated during winter equinox where it provides results when the sun is perimetering at its maximum position at the Tropic of Capricorn. This study applies simulation analysis for of the case study using Autodesk software known as *3DStudio Max* programme. This programme creates simulation of the illuminance level to the indoor building areas during winter season when the sun is perimetering at its most southern point along Tropics of Capricorn. A weather file is inserted in the programme during simulation process as a tool to gain accurate condition of the local weather. The analysis shows that mosque with pedentive dome design provides evenly distributed illuminance level with Scale 2 and 3 lighting performance inside the mosque compared to pyramid roof design only with Scale 2. The study concludes that having better illuminance level distributed at all the locations is one of the crucial reasons why the mosques with pedentive dome roof cover are popularly built in Bosnia as well its neighbouring regions by the Ottoman master builders.

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Keywords: illuminance; pedentive dome; pyramid roof; Mostar

1. Introduction

This study aims to identify with reference to indoor lighting performance why pedentive dome is very popular roof form in the mosque design since this type of dome was introduced during the reign of Ottoman Empire in

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Bosnia as well as its neighbouring provinces in Balkan region. Assessment to obtain result of illuminance level is this research approach to measure the lighting performance inside the building. The focus of this study is to compare results of indoor lighting performance between pedentive dome and pyramid roof mosque by using lighting simulation analysis created in a computer programme known as 3dStudio Max 2010. Karadgoz Beg Mosque represents pedentive dome mosque whereas Neziraga Mosque exemplifies pyramid roof mosque which are rarely built in Ottoman architecture. Both of these mosques are located in Mostar, Bosnia Herzegovina about 500 metres apart from each other. Adoption of pedentive dome concept had made possible for a mosque design with vast interior and 'double space' in height; as a result, the design with excellent natural lighting is necessary which it reflects its impact on architectural grandeur.

It is an ingenious works of Ottoman master builders by reinventing the pedentive dome concept of Hagia Sophia's architecture translated to more elaborated lighting performance from natural sunlight in the mosque design (Necipoglu, 2007) [7]. The idea is to transmit the sunlight into the interior space from upper window openings at the projected primary and secondary domes that besides intensifying a sense of sacredness (Hillenbrand, 1994) [5]. Mosques with 'pedentive dome' for roof construction are popular compared to pyramid roof form in this region. Pedentive dome design is a basic construction in Ottoman as well as Byzantium architecture. Pedentive dome means a construction of 'dome built above dome' concept, a dome design in a way as if it is 'hanging in the air' over four giant arched supports (Mango, 1976).

The uniqueness is that it has a large double space design to the mosque interior. During this time, the construction technology complies with load bearing technique. The dome has no structural system, therefore; it bears its own weight. The upper dome is supported by four grand arches which constitute as the lower dome. The advantage of this construction is that it consumes efficient usage of building material such as stones, bricks and marbles for the construction which leads to dematerialised concept of the building construction.

2. Methodology

Indoor lighting performance of these two mosques in this study is evaluated based on the illuminance level. This illuminance level used is measured in lux or lumen per metre square (lumen/m^2), which means the amount of luminance (lumen) affected on a 1m x 1m surface area. By referring to this measurement, the study can determine the indoor lighting performance by using comparative analysis between pedentive dome and pyramid roof form (Runsheng, Meir & Etzion, 2009) [10]. Building design using daylight system is considered as having excellent passive design. Daylight is lighting obtained from indirect sunlight source. It provides the best source which comfortably matches with human visual response. The amount of daylight's penetration into a building is mainly through sunlit area from window and door openings which provide the dual function not only of admitting natural light to the indoor environment but also allowing the occupants to have visual contact with the outdoor environment (Chel, Tiwari, & Chandra, 2009; Chel, Tiwari & Singh, 2009) [1] & [2].

2.1. The Case Study

Like in other parts of the Ottoman Empire, mosques in Bosnia during the same the period had played an important symbol of the regional architecture, portraying the belief, culture and politics of the Muslim society (Saoud, 2004) [11]. Mostars is a small city in Bosnia located at the both sides of Neretva River and was once under the Ottoman Empire (Pasic, 2004) [9]. This city is located in Balkan Region. By fifteenth century, most of this region is under Ottoman Kingdom (Pacic, 1990) [8]. Most mosques in this region were built during this period with two types of roof form used in the mosque construction which are dome and pyramid roof form.

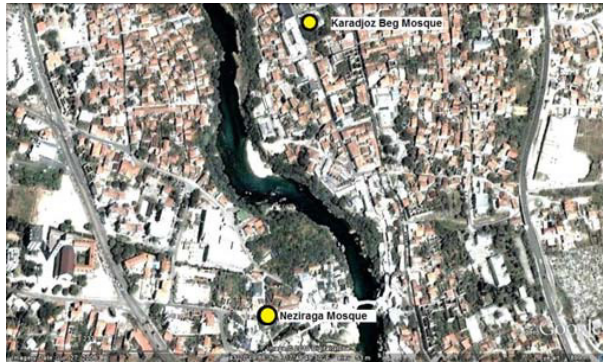
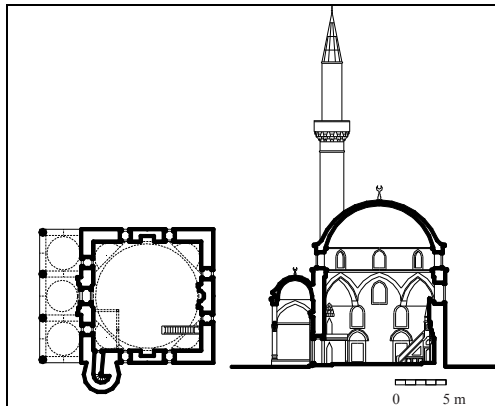


Fig. 1. Location of Karadjoz Beg and Neziraga mosque. Photo's source: Google Earth

This study selected two mosques located in the city of Mostars for the case study. The reason for this selection is that there are two mosques, one with dome and the other one with pyramid roof form located in this city less than 500 metres, a distance to each other (Figure 1). With this distance away, the study can relatively generate as minimum possible the error in the results of the simulation and comparative study between these two mosques during the analysis. The selected mosques in this case study are Karadjozbeg and Neziraga mosque.



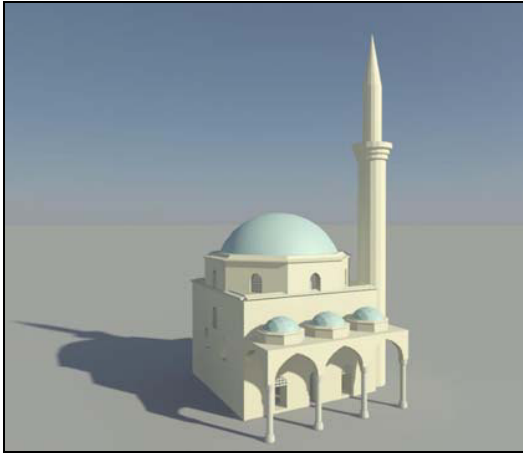


Fig. 2. Karadjoz Beg mosque plan and section (top), and 3D perspective (bottom)

Karadjoz Beg mosque is an example of single pendentive dome mosque design with one minaret (Serageldin, 1989) [13] as illustrated in Figure 2. It was built in 1557. This type of dome design has the simple plan unit layout in Ottoman mosque construction which consists of basic square and round dome geometric elements. The dome is an element for roof cover to the main prayer hall and its design had progressed from time to time in Ottoman architecture to complexed dome construction with combination of domes' design (Necipoglu, 2007) [7]. The bigger the dome is, the larger is the size of its main prayer hall. The reason is that the dome of this single plan unit design attributes to single pendentive dome roof cover built at the centre of the mosque. The most discrete characteristic of this single dome plan design is that it has a dominant pendentive dome roof. The plan has 13m length and 13m width. The building height is 15.9m where the dome radius is 6.17m. Its attached hipped roof form covering the *riwaq* is not part of this analysis as it was not element of the Ottoman mosque design.

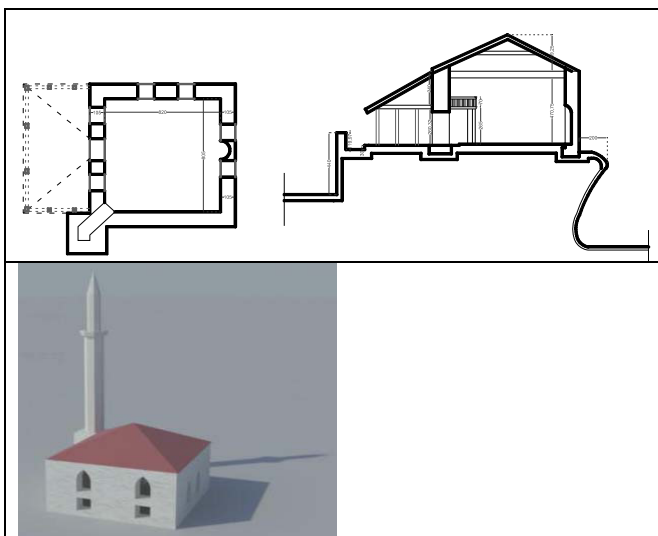


Fig. 3. Neziraga mosque plan and section (top), and 3D perspective (bottom)

Neziraga mosque is the other selected building for the case study as illustrated in Figure 3. Its location is closed to Mostar Old Bridge. This mosque has a single pyramid roof form with one minaret. The mosque was built in 1550 but it was closed in 1930 and later torn down in 1950, left derelicted not until it is reconstructed in 1999 under UNESCO rehabilitation plan and IRCICA's (Research Centre for Islamic History, Art and Culture) Mostar 2004 programme with cost of USD453,000. The mosque name is taken from the name of a person, Neziraga who was a local novel family from a highly respected Vucjakovic family (Serageldin, 1989) [13]. It is located at elevated hill platform east of Neretva River at distance of 150 meter from the old bridge of Mostar. This mosque has a design of simple plan unit layout comprising basic square plan with pyramid roof type. This single pyramid roof covers the main prayer hall. The most discrete characteristic of this single plan design is that it has a dominant pyramid roof. This mosque has a square plan design with 10.2m width and 10.2m length. Its height is 7.77m with its roof's height at 2.59m.

2.2. Method of Simulation

The scope of this survey is to simulate the indoor's lighting performance of Karadjoz Beg and Neziraga mosque in Mostar and to do comparative analysis of the results between these two mosques. This simulation is conducted on 21st December 2010 on the day of the winter equinox's occurrence when the sun path is at its highest latitude of the northern hemisphere along the Tropic of Capricorn. This daylight simulation is a computer-based calculation of the amount of daylight inside the building using 3dStudio Max programme.

Before simulation analysis is conducted, three dimension drawings of these two mosques are created using AutoCAD software based on one to one scale illustrating exact measurement of the building form with reference to the mosque's two dimensional AutoCAD plan and section. After that, these three dimension drawings are imported to 3D Studio Max 2010. A daylight system is created in this programme, and a camera view is set to the top view (perspective) before lighting analysis can be generated.

A specific local daylight system is inserted in this programme using the available weather data file of Banja Luka (44°49'N and 17°11'E), the nearest a city to Mostar (43.34 N latitude and 17.81 East longitude). This weather file is downloaded from weather data files (*.EPW) (EnergyPlus 2010) [3], which contain annual data for typical climatic conditions at this site. It will provide data with respect to the local climatic condition.

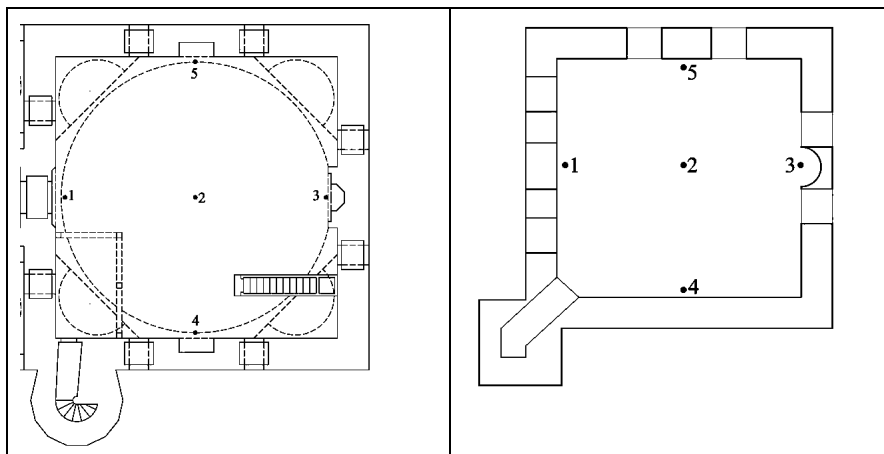


Fig. 3. Selected 5 points inside the prayer hall in the Karadjoz Beg (top) and Neziraga (bottom) mosque

A light metre is created by setting points of incidence which show the illuminance level. Each subdivision represents a point at which incident illuminance normal to the grid (1 m x 1 m) will be measured (calculated). It provides overlaying a grid of illuminance results. This simulation is created after identifying a light meter at human body level 450 mm (when sitting on the ground while praying and listening to the Friday's sermon) above the ground floor plan of the mosque. The results are based on its reference to this light meter's setting with modification of the daylight system to the selected weather file (Landry & Breton, 2009) [6]. Selected points on the imaginary grid plan layouts are used in the measurements during this simulation.

Duration of this simulation is only scoped to 12 hours with one hour interval for each measurement taken from 6:00am to 6:00pm on 21st December 2010. The simulation does not taken account to the time of sunrise and sunset when the measurements are collected. Each hour is represented by lighting analysis calculation per frame in one rendering image at resolution 1024 x 768. This analysis is to test indoor illuminance level by simulating the realistic atmosphere from weather file's data at selected 5 points (P1=entrance door; P2 centre prayer hall; P3=*mihrab*; P4=right side prayer hall; and P5=left side prayer hall) inside the building for each mosque (Figure 5). The results for each selected points is collected and then converted to tables and line charts. These results allows us to have comparative analysis of lighting performances between Karadjoz Beg and Neziraga mosque. This analysis refers the measurable scale of the illuminance level as follows (Schlyter, 2010; Wikipedia, 2010) [12] & [14]:

Table 1. Lighting scale of measurement

Scale	Illuminance (lux)	Level
1	0	Total darkness
2	1 - 79	Dark (less than hallway brightness)
3	80 - 199	Hallway brightness
4	200 - 500	Brightness for reading or office area
5	501 - 1000	Brightness for intricate work
6	1001 - 10000	Brightness from direct sunlight to indoor area
7	10001 - 100000	Outdoor area brightness from direct sunlight 100000 lux is the maximum measurement.

3. Results of Analysis

The results of analysis from computer simulations at Point 1, 2, 3, 4 and 5 from the selected mosques are as follows:

3.1. Point 1

The graph in figure 4 shows that point 1 in Karadjoz Beg mosque has higher level of illuminance in all hours of simulation than point 1 in Neziraga mosque. Karadjoz Beg mosque's Line Chart starts with 31.5 lux at 7:00am then rises symmetrically to reach the peak in the noon at 11:00am with 211.2 lux whereas in Neziraga, the Line Chart starts with 13.4 at 7:00am then reaches its peak at 9:00am with 75.4 lux. Both mosques has the lowest level of illuminance at 3:00pm with 24.3 lux in Karadjoz Beg and 7.17 lux in Neziraga then go to 0 lux at 4:00pm. The results show that in Karadjoz Beg has daylight from 9:00am until 2:00pm which provides good illuminance level under scale 3 except 11:00am under scale 4 while in the morning and in sunset time the illuminance level is under scale 2. Neziraga mosque has lower illuminance level than Karadjoz Beg under scale 2 in all day hours. In

comparison, the average of illuminance level in Karadjoz Beg mosque is three times higher than that of Neziraga mosque.

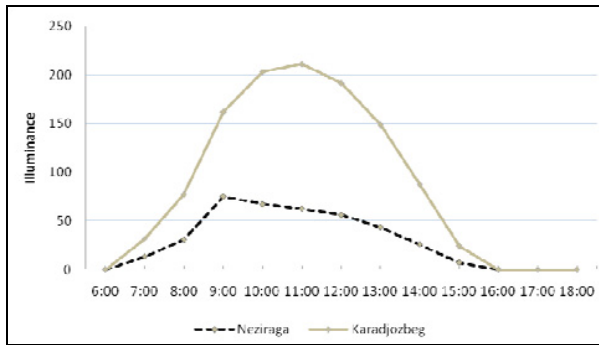


Fig. 4. Line chart of Point 1

3.2. Point 2

Figure 5 shows that point 2 which is located in the central of prayer hall in both Karadjoz Beg and Neziraga mosque has low illuminance level ranging from 5 to 112 lux. Sunlight provides good illuminance level from 9:00am till 12:00pm in Karadjoz Beg mosque under scale 3 of the lighting scale measurement while other times are under scale 2. The Line Chart of Karadjoz Beg mosque starts with 31.5 lux at 7:00am then increase sharply to reach the maximum illuminance level at 10:00am with 112.3 lux, after that goes down to stop at the minimum level at 3:00pm with 10.4 lux. Results for Neziraga mosque shows that the Line Chart stay less than Karadjoz Beg's Line Chart without any intersection points, starting from 10.9 lux at 7:00am to its maximum point at 10:00am with 51.3 lux, then starting decline slowly with 47.7, 38.8, 29.6 and 17.5 lux at 11:00, 12:00, 1:00 and 2:00pm to reach its minimum illuminance level at 3:00pm with 4.88 lux. These illuminance levels of Neziraga mosque come under scale 2 in all hours of simulation during the daytime.

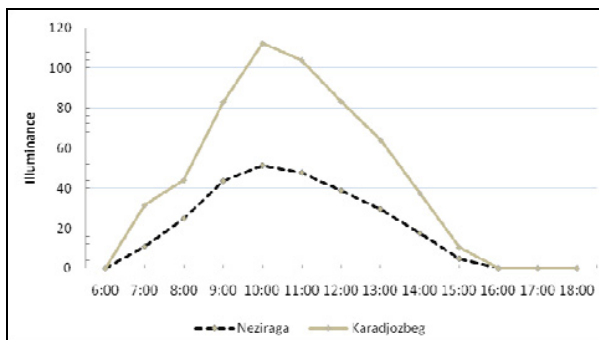


Fig. 5. Line chart of Point 2

3.3. Point 3

Figure 6 shows that the illuminance levels at Point 3 (location near the *mihrab*) in Karadjoz Beg mosque are brighter than those in Neziraga mosque in the simulation ranging from 8 to 78 lux. Karadjoz Beg mosque has

higher illuminance levels than Neziraga mosque which ranging from 3 to 38 lux. There is no intersection point in the Line Chart of Point 3. The afternoon sunlight provides higher illuminance level than those in morning and evening sunlight. The average illuminance level at mosque Karadjoz Beg is 46.3 lux which is more than two times higher than that of Neziraga mosque (19.5 lux). Neziraga mosque starts with illuminance level of 8 lux at 7:00am and goes up to 37.7 lux at 10:00am then decrease gradually with 30.6, 23.8, 18.3 and 10.8 lux at 11:00am, 12:00, 1:00 and 2:00pm respectively to 3 lux at 3:00pm. The results show that Karadjoz Beg mosque's Line Chart goes up sharply to reach the maximum illuminance level then decline sharply to 0 lux at 4:00pm whereas the Line Chart of Neziraga twice lower than that of Karadjoz Beg mosque. The sunlight provide illuminance levels under schale 2 in both of the mosques in all the daytime hours.

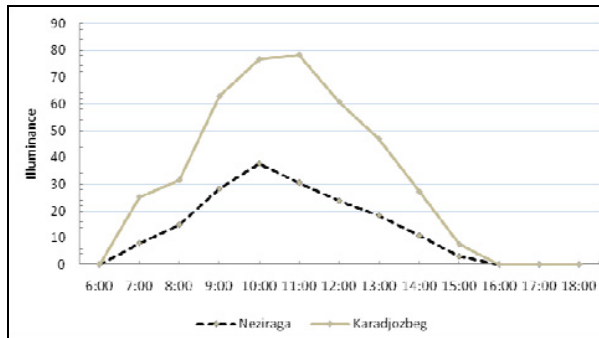


Fig. 6. Line chart of Point 3

3.4. Point 4

Figure 7 shows that illuminance at Point 4 (location near south-west wall) at both of the mosques has the same behavior with almost similar results that Neziraga Mosque has slightly lower illuminance levels than that of Karadjoz Beg mosque. Karadjoz Beg mosque's Line Chart starts with 29.7 lux at 7:00am then increases every one hour with 35, 67.1 and 83.6 lux at 8:00, 9:00 and 10:00am respectively, and declines with 80.9, 61.1, 52.4, 30.6 and 8.5 lux at 11:00, 12:00am, 1:00, 2:00 and 3:00pm respectively. The figure illustrates that all the morning and evening sunlight hours have illuminance levels under scale 2 except only at 10:00 and 11:00am at Karadjoz Beg mosque under scale 3. The illuminance results of Neziraga mosque range from 14.2 to 69.5 lux. The illuminance levels at Neziraga mosque from 7:00am to 3:00pm are less than 80 lux under scale 2 in lighting scale of measurement. The average illuminance level at Karadjoz Beg mosque (50 lux) is 10 lux higher than that of Neziraga mosque (40 lux).

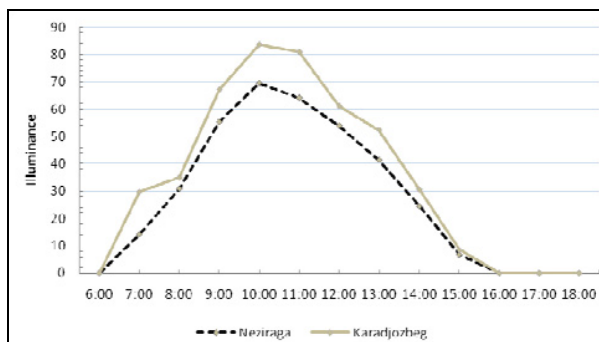


Fig. 7. Line chart of Point 4

3.5. Point 5

Figure 8 shows that illuminance levels at Point 5 (location near north-east wall) in Karadjoz Beg mosque range from 7.2 to 78.8 lux, less than 80 lux with its maximum of 78.8 lux at 10:00am all categorised under scale 2. The illuminance level start with 26.3 lux at 7:00am and 29.5 at 8:00am then increases two times higher illuminance level at 9:00am with 63.7 lux to its maximum level (78.8 lux) at 10:00am before starting to decrease progressively at 11:00, 12:00, 1:00 and 2:00pm with 71.4, 66, 44.3 and 25.8 lux respectively to reach the minimum illuminance level at 3:00pm with 7.2 lux. Neziraga mosque however has less brightness compared to those in Karadjoz Beg mosque at all hourly simulations.

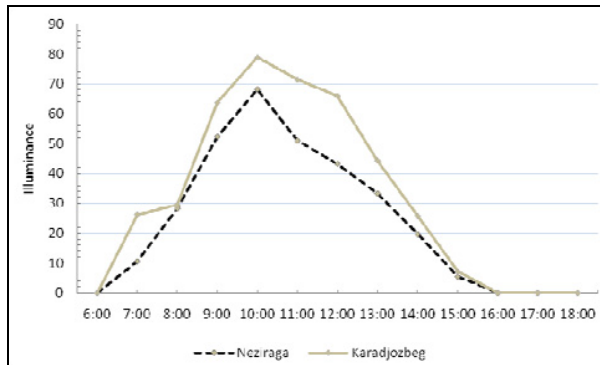


Fig. 8. Line chart of Point 5

The Line Chart shows that the illuminance begins with 10.6 lux at 7:00am similar to Karadjoz Beg mosque's Line Chart rising with 28.3, 52.3 lux at 8:00 and 9:00am respectively then reaches at its peak with 68.2 lux at 10:00am (maximum illuminance level) before goes down to reach its minimum level with 4.5 lux at 3:00pm from 51, 43.3, 33.3, 19.7 lux at 11:00, 12:00, 1:00, 2:00pm respectively. Karadjoz Beg mosque has its brightness from 7:00am to 3:00pm ranging from 7.2 to 78.8 lux while Neziraga mosque has its luminance level ranging from 7:00 to 3:00pm with 5.5 to 68.2 lux respectively. All illuminance levels are under category Scale 2 in both of Karadjoz Beg and Neziraga mosque in all the simulation hours.

4. Discussions

The findings from the results of analysis are as follows:

- Pedentive dome design has higher illuminance levels in its indoor area than pyramid roof design. The line charts shows that all the illuminance levels at Karadjoz Beg mosque are brighter than those in Neziraga mosque in all hours during the daytime. The result besides shows that Karadjoz Beg mosque has relatively about three times higher average illuminance levels compared to Neziraga mosque at point 1 of the simulations and twice higher at point 2 and 3 while they are similar to each other at point 4 and 5. Karadjoz Beg mosque has an average of 126 lux at Point 1, 63 lux at Point 2, 46 lux at Point 3, 50 lux at Point 4 and 46 lux at Point 5 in contrast to an average of 43 lux at Point 1, 30 lux at Point 2, 20 lux at Point 3, 40 lux at Point 4 and 35 lux at Point 5 in Neziraga mosque.

- Karadjoz Beg mosque has evenly distributed illuminance levels in its indoor area under category Scale 2 and 3 (hallway brightness) at Point 1, 2 and 4; and Scale 2 less 80 lux for Point 3, 4 and 5. Neziraga mosque on the other hand has poor lighting performance in term of evenly distributed illuminance levels in its indoor area compared to those in Karadjoz Beg mosque as is illustrated in Figure 9 and 10, and Table 2 and 3. Most illuminance levels fall under category Scale 2 at Point 1, 2, 3, 4 and 5.
- The result shows that pedentive dome design provides illuminance level to all locations inside the mosque better than pyramid roof design which has poor evenly distributed illuminance level especially at the location near to *mihrab* with low illuminance and at other locations.

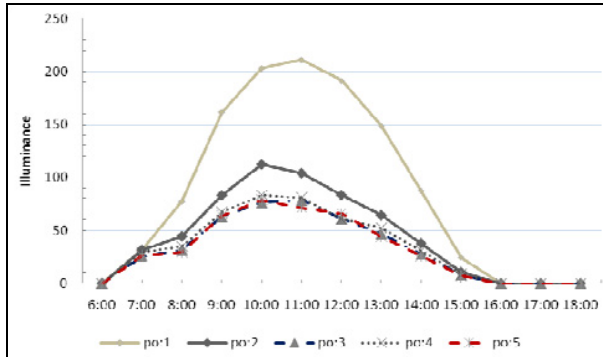


Fig. 9. Line chart of Karadjoz Beg mosque at Point 1, 2, 3, 4 & 5

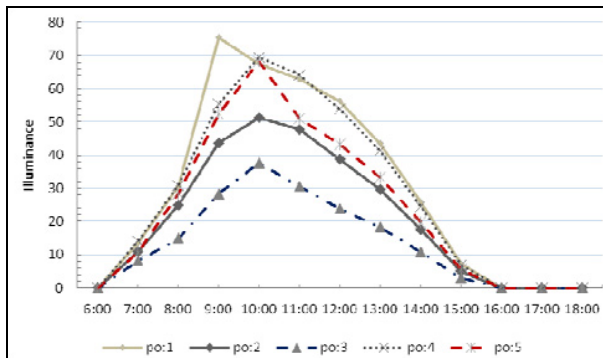


Fig. 10. Line chart of Neziraga mosque at Point 1, 2, 3, 4 & 5

Table 2. Indoor illuminance level of Karadjoz Beg Mosque

Time	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00
Point 1	0	31.5	77.1	161.8	203.3	211.2	191.5	148.9	87.4	24.3	0	0	0
Point 2	0	31.5	44.1	83	112.3	103.9	83.2	64.1	37.5	10.4	0	0	0
Point 3	0	25.2	31.5	62.8	76.6	78.3	60.8	46.9	27.2	7.59	0	0	0
Point 4	0	29.7	35	67.1	83.6	80.9	61.1	52.4	30.6	8.53	0	0	0
Point 5	0	26.3	29.5	63.7	78.8	71.4	66	44.3	25.8	7.2	0	0	0

Table 3. Indoor illuminance level of Neziraga Mosque

Time	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00
Point 1	0	13.4	30.5	75.4	67.4	62.8	56.3	43.5	25.8	7.17	0	0	0
Point 2	0	10.9	24.9	43.6	51.3	47.7	38.8	29.6	17.5	4.88	0	0	0
Point 3	0	8.01	14.9	28.3	37.7	30.6	23.8	18.3	10.8	3.01	0	0	0
Point 4	0	14.2	30.9	55.3	69.5	64.1	53.9	41.4	24.5	6.81	0	0	0
Point 5	0	10.6	28.3	52.3	68.2	51	43.3	33.3	19.7	5.48	0	0	0

5. Conclusion

This study concludes that single pedentive dome design has better lighting performance than single pyramid dome design. It has better evenly distributed illuminance level at all locations inside the mosque in comparison to single pyramid roof design. This result supports the argument why pedentive dome is very popularly built for the mosque roof form in Bosnia by the Ottoman master builders from Asia Minor. By applying pedentive roof form, it gives inspiration to the master builders to design a mosque with excellent natural lighting performance transmitted into the mosque at various angles to provide evenly distributed illuminance level at all locations. The design creates vast interior space plan layout without obstruction by walls and columns providing excellent sunlight penetration into the building (Goodwin, 1993) [4]. This offers the master builders besides to explore lighting design as a source of expression leading toward a sense for a place of worship with a presence of divinity inside the building. Location near the *mihrab* is the most important because it is the place where congregational prayers five times a day, sermon and lectures (*kuliah*) take place, therefore; having satisfactory illuminance levels at this area during winter time is necessary.

Acknowledgements

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