Research of light environment of university libraries in class IV light-climate areas -- taking the library of Shandong women’s university as an example

Zengzhang Yang*
Library of Shandong Women’s University, Jinan, 250300, China

*Corresponding author e-mail: wuyegl@163.com

Abstract. Class IV light-climate areas have the relatively lower average annual total illumination. Characteristics of the light climate exert a direct influence on natural lighting of the reading rooms in libraries. According to national standards such as Architectural Day Lighting Design Standards, Library Architectural Design Specification and Architectural Lighting Design Standards, the paper discusses the light environment of the library in Shandong Women’s University in order to provide the reference for improvement of light environment of class IV light-climate areas and building the congenial reading environment through the practical measure of light environment in reading rooms of the library, questionnaire surveys and data analysis.

1. Introduction
Geographical parameters of Jinan (east longitude 116°59′, north latitude: 36°40′), is the area belonging to class IV area of China's five light climate zones, whose average annual total illumination is low, natural light average total illumination is between 30klx and 35klx, the outdoor natural light design illumination value Es is 13500 lx, and the outdoor natural critical illumination value El is 4500 lx. The climatic characteristics of the Jinan area directly affect the natural light level of the library reading room. The light environment is an important component of the library environment. Light intensity is too strong or too weak to be a disadvantage to readers' reading and learning. It will cause readers to fatigue their eyes and affect their mood.

Shandong Women's University is located in Changqing University Science Garden in Jinan. The new library was completed and put into use in November 2009. The library is a four-story building. On the 1st to 4th floors of the south and west, there is an open reading room that is a combination of books and magazines. The first floor on the north side is the school exhibition room and the periodical reading room, the second floor is the reference book reading room and the basic stack room, the third floor is the electronic reading room, and the fourth floor is the self-study room. The middle is a patio-style hall. The roof of the hall is a glass roof. Each floor around the hall is a circular corridor with good natural daylighting. In the reading room, there is a large bay layout, and the exterior wall uses a large-area glass window with plenty of natural light. In order to make full use of natural light, the reading area in the reading rooms is located near the window. The reading room lamps and lanterns are all made of metal mesh plate light channels, and narrow diameter straight tube fluorescent lamps that are ceiling-mounted and arranged at equal intervals with the soft and comfortable light.
Taking the library of Shandong Women's University as an example, the author carries out measurement on the spot, questionnaire survey and data analysis of the natural daylighting and artificial lighting in the reading rooms and provided references for improving the light environment and creating a good reading environment of university libraries in the class IV light-climate areas.

2. Materials and methods of research

2.1. The location and time of measurement
This survey selects ordinary reading rooms, self-study rooms, and electronic reading room often used by readers as objects for natural daylighting and artificial lighting research. The measurement of natural daylight is conducted on a full cloudy day. Time difference is within 30 minutes between outdoor daylighting point measurement and indoor daylighting point measurement. At the same time, the lighting data in the reading room during sunny days is also taken as a reference [1]. Artificial lighting measurement is conducted after night darkness. First, the staff is required to open all undamaged lamps and confirm that the lamps have been turned on for more than 40 minutes. After the lamp illumination is stable, the illumination of the working surface is measured [2].

2.2. Materials and methods of measurement
Digital illuminometer and a tape measure are used as measuring instruments. The illuminometer has a measurement range of 0.1 to 500000 lx, a minimum resolution of 0.1 lx, and an accuracy of ±3% or less. The field measurement includes the spatial data of the research site and the relevant data of the light environment. The spatial data mainly includes the height of the indoor work surface, the distance from the lamp to the work surface, the number and spatial arrangement of the lamps, etc. The light environment data mainly includes the monitoring points of each work surface illumination.

Natural daylighting measurement is performed according to GB/T5699-2008 Daylighting Measurement Method. When the outdoor natural lighting is measured, the unoccupied open space or the roof of the building should be selected. The receiver should be placed at a distance of more than 6 times the height of the obstruction from the surrounding buildings or other shelters. The natural daylighting illumination in the reading room is the horizontal illumination of the working surface of the reading area [3].

Artificial lighting measurement takes GB/T5700-2008 Lighting Measurement Method as the reference. The general reading room is measured its horizontal illumination of the desktop, and the illumination of the horizontal working surface is measured in the self-study rooms and the electronic reading room. The horizontal operation surface adopts the central site measurement method. The area of the rectangular grid is 2m×2m. The height of operation of reading area of the electronic reading room and the ordinary reading room is 0.75m. The measuring surface of the bookshelf area is 0.25 meters away from the vertical surface and the illumination of the center points of each rectangular grid is measured [4].

2.3. Questionnaire surveys
Questionnaires are distributed randomly and collected on the spot and recovered. The questionnaire surveys on the library's light environment from five aspects: the readers’ residence time in the library, the evaluation of the library's natural daylighting environment, the satisfaction to the library's lighting system, and the appropriateness of the lighting illumination of the reading rooms. A total of 368 questionnaires are distributed at the library's ordinary reading rooms, self-study rooms, and electronic reading room. 350 valid questionnaires are collected on the spot, and the questionnaire recovery rate is 95.1%. The respondents are the users of the Shandong Women's University library. Most of them are students, and a few are staff.
2.4. Envaluation standards

According to the GB50033-2013 Architectural Daylighting Design Standards, table 4.0.9 library building lighting standards, library lighting levels in the general reading room should not be less than the level III requirements. In the side lighting, the standard value of the daylighting factor is 3%, and the standard value of natural light in the reading room is 450lx. According to the JGJ38-2015 Library Building Design Code, table 7.2.1 various types of rooms of library or places of natural lighting standard value, library lighting level of electronic reading room should not be less than the level IV requirements. Lighting level of basic stack room, corridors, staircase and the toilets should not be less than the IV level requirements. Table 1 is shown.

| Lighting level | Locations                          | Side daylighting |                      |
|----------------|------------------------------------|------------------|----------------------|
|                |                                    | Standard value of| Standard value of   |
|                |                                    | daylighting factor (%) | indoor natural light illumination(lx) |
| III            | Reading rooms, open shelf          | 3.0              | 450                  |
| IV             | Electronic reading room           | 2.0              | 300                  |
| V              | Basic stack room, walkways, staircases, toilets | 1.0 | 150                  |

The standard value of the lighting factor listed in Table 1 is applicable to China's Class III light-climate zone. The standard value of the daylighting factor is based on the outdoor design illumination value of 1500lx.

According to the GB50033-2013 Architectural Daylighting Design Standards, table 3.0.4 K value of the light climate factor, the standard value of the lighting factor in the region should be multiplied by the corresponding regional climate factor K. Jinan belongs to class IV light climate zone, and the light-climatic factor is 1.1, so the daylighting factor of the library reading room in Jinan is 3%×1.1=3.3%, and the electronic reading room is 2%×1.1=2.2%, the basic library is 1%×1.1 = 1.1%.

According to JGJ38-2015 Library Building Design Code table 8.3.5 Library of all types of rooms or places of lighting design standard value, and GB50034-2013 Architectural Lighting Design Standards table 5.3.1 library building lighting standard value, the illumination standard is 300 lx in library's ordinary reading rooms, open shelf, and electronic reading room. The illumination standard of the library shelf is 50 lx. The lighting power density is 9 W/m², and the illumination uniformity U₀ is not less than 0.6. See Table 2.

| Locations                  | Reference plane and height(m) | Illumination standard (lx) | Lighting power density(W/m²) | Uniformity of illumination U₀ |
|----------------------------|-------------------------------|----------------------------|-----------------------------|-------------------------------|
| Ordinary reading rooms, open shelf | 0.75 (horizontal)           | 300                        | 9                           | 0.6                           |
| Electronic reading room    | 0.75 (horizontal)            | 300                        | 9                           | 0.6                           |
| Stack room, book shelves   | 0.25 (vertical)              | 50                         | null                        | 0.6                           |
3. Results

3.1 The survey results of natural daylighting

Through field measurement and calculation, Table 3 shows the values of natural daylighting illumination of each reading rooms of the library. The average illumination of natural light and daylighting factors are both lower the standard values in southward and westward reading rooms on the first floor and the reading area of the periodical reading room. The average illumination of natural light and daylighting factors have reached the standard values in reading areas of other southward and westward rooms. The average illumination of natural light and daylighting factors fail to reach the standard values in reading areas of all northward rooms. The average illumination of natural light and daylighting factors fail to reach the standard values in bookshelves areas of all reading rooms. Thus, it can be seen that there is enough natural daylighting in reading areas of southward and westward reading rooms, while the artificial lighting is needed as an assistance in southward periodical reading room with large depth, reading areas of northward rooms and bookshelves areas of all reading rooms.

| Locations                        | Outdoor illumination (lx) | Average indoor illumination(lx) | Daylighting factor (%) | Orientation |
|----------------------------------|---------------------------|---------------------------------|------------------------|-------------|
|                                  |                           | Reading area | Bookshelves area | Reading area | Bookshelves area |           |
| The first books lending room     | 13489                     | 433         | 74              | 3.21        | 0.55          | Southward |
| The second books lending room    | 13396                     | 430         | 71              | 3.21        | 0.53          | Westward  |
| The third books lending room     | 13540                     | 459         | 91              | 3.39        | 0.67          | Southward |
| The fourth books lending room    | 13462                     | 455         | 89              | 3.38        | 0.66          | Westward  |
| The fifth books lending room     | 13588                     | 462         | 96              | 3.4         | 0.71          | Southward |
| The sixth books lending room     | 13501                     | 455         | 93              | 3.37        | 0.69          | Westward  |
| Children’s picture gallery       | 13636                     | 465         | 110             | 3.41        | 0.81          | Southward |
| Periodical reading room          | 13566                     | 369         | 106             | 2.72        | 0.78          | Westward  |
| Back issues reading room         | 9317                      | 191         | 48              | 2.05        | 0.51          | Northward |
| Electric reading room            | 9679                      | 211         |                 | 2.18        |               | Northward |
| Self-study rooms                 | 9729                      | 215         |                 | 2.21        |               | Northward |

3.2 Survey results of artificial lighting

Through actual measurement and calculation, the library's artificial lighting illumination measurement data is shown in Table 4. From this, it can be seen that the average illumination of the reading areas on the first to fourth floors is between 143 and 208 lx, all lower than the standard value (300 lx), and the average illumination on the bookshelf area is between 36 to 47 lx, also lower than the standard value (50lx). Each floor reading room illumination uniformity is lower than the standard value (0.6). Reading room design lighting power density is 10W/m2, in line with the standard value. However, the damage
rate of lighting fixtures is very high, and the damage rate of reading lamps in each reading room is between 12% and 33%.

3.3. Results of the questionnaire survey

Regarding to readers' residence time in the library, 17% of the respondents choose to stay in the library for less than one hour, 32% of respondents for 2-3 hours, and 51% for more than 3 hours. See Figure1.

The readers' evaluation of the library's natural daylighting environment: when it is sunny, 78% of readers believe that the light is suitable, and 22% believe that the light tends to be strong. On rainy days, 53% of readers believe that the light is weaker, and 18% believe that the light is too weak, and only 29% believe that the light is suitable. See Figure 2 and Figure 3.

| Table 4. The library's artificial lighting illumination measurement |
|---------------------------------------------------------------|
| Locations | Minimum illumination(lx) | Average illumination(lx) | Illumination uniformity | Damage rate of reading lamps (%) |
|-----------|--------------------------|--------------------------|-------------------------|----------------------------------|
| The first books lending room | Reading area | 59 | 155 | 0.38 | 22 |
| | Bookshelves area | 11 | 38 | 0.29 | 25 |
| The second books lending room | Reading area | 63 | 175 | 0.36 | 20 |
| | Bookshelves area | 12 | 42 | 0.28 | 23 |
| The third books lending room | Reading area | 49 | 152 | 0.32 | 33 |
| | Bookshelves area | 10 | 36 | 0.28 | 31 |
| The fourth books lending room | Reading area | 77 | 207 | 0.37 | 20 |
| | Bookshelves area | 14 | 43 | 0.33 | 22 |
| The fifth books lending room | Reading area | 74 | 191 | 0.39 | 18 |
| | Bookshelves area | 13 | 46 | 0.28 | 21 |
| The sixth books lending room | Reading area | 82 | 200 | 0.41 | 13 |
| | Bookshelves area | 15 | 47 | 0.31 | 15 |
| Children’s picture gallery | Reading area | 106 | 208 | 0.51 | 12 |
| | Bookshelves area | 18 | 45 | 0.39 | 16 |
| Periodical reading room | Reading area | 69 | 178 | 0.39 | 19 |
| | Bookshelves area | 16 | 47 | 0.35 | 17 |
| Back issues reading room | Reading area | 39 | 143 | 0.27 | 31 |
| | Bookshelves area | 10 | 39 | 0.25 | 32 |
| Electronic reading room | 49 | 159 | 0.31 | 32 |
| Self-study rooms | 80.41 | 187 | 0.43 | 13 |

Of the readers' evaluation of the library's artificial lighting system, respondents who are satisfied account for 21%, relatively satisfied account for 52%, and unsatisfied account for 27%. See Figure 4.
Of the readers' evaluation of the illumination of the library’s reading rooms, respondents who consider the lighting illumination suitable account for 62%. 22% of respondents consider the light illumination relatively dark and 16% consider it is too dark. See Figure 5.

Of the readers' opinions and suggestions on the library's light environment, 71% respondents put forward opinions and suggestions, of which 56% propose to repair damaged lamps in time to increase lighting. See Figure 6.

Through the statistical analysis of the questionnaire data, the survey results confirmed that people's subjective feelings are basically consistent with the measured data.
4. Conclusions and suggestions
Through field measurement of illumination of natural daylighting and artificial lighting of the library of Shandong Women’s University, calculation of illumination uniformity, daylighting factors, lighting power and making a comparison with national standard values combined with the results of questionnaire surveys to analyze, conclusions drawn are as follows:

4.1. Artificial lighting
The designed lighting power density of the library meets the architectural lighting design standards, but the actual artificial illumination and illumination uniformity are lower than the architectural lighting design standards, so readers keep lower satisfaction.

4.1.1. Analysing reasons are as follows. (1) Although the design lighting power density of the reading rooms meets the standards, the damage rate of the lamps is high. The original design of the lighting power density is not guaranteed, and the illumination and illumination uniformity are also insufficient; during the research, it was also found that some of the metal mesh lamp channels have come off, which weakens the effect of softening the light and reducing glare.

(2) The luminaire's control switch settings are inappropriate. Each switch controls multiple lights in the reading areas and the bookshelf areas at the same time. The natural lighting of the bookshelf areas is insufficient and requires artificial lighting throughout the day. The natural lighting of the reading area is pretty good though, the switch controls the reading area and the bookshelf area at the same time, which causes the lights in the daytime have to turn on so that not only the lamps are easily damaged, but also electricity is wasted. The library is open daily from 8:30 am to 9:30 pm, which means lighting time is long, and the lamps are easily damaged by aging.

(3) Maintenance expenses and labor shortages are incapable of timely repair and replacement of bad lamps.

4.1.2. Suggested measures are as follows Switch settings should be improved that reading areas and bookshelf areas are respectively controlled. Sensor lights can be installed on the bookshelf area so that it cannot only save electricity but also improve the light environment and can avoid light pollution caused by long-time light. Maintenance should be normalized and regular maintenance should be kept. It is best to check once a week to replace bad lamps in time [5].

4.2. Natural daylighting
Natural daylighting of most of the library's reading areas is in line with the architectural lighting construction standards, but the bookshelf area lighting illumination is insufficient. After artificial lighting as the assistance, the readers’ satisfaction is higher. However, in the high-level reading area, there exists phenomena such as strong sunlight and large glare.

4.2.1. Reasons analyzed are as follows the large-area glass window of the library's exterior wall and the design of the center glass roof hall make plenty of natural light, but it will inevitably produce strong light and strong solar radiation, and it will cause high indoor temperatures in summer and autumn, affecting the reader's vision comfort and thermal comfort experience. On-site research sees the books on the shelf near the west window has been whitish, and some readers in order to avoid strong sunlight, move the chair to the middle of the bookshelf to study.

4.2.2. Suggested measures A safety insulation film can be covered on the inside of the western glass window of the reading room and dark curtains can be installed in the reading room. When the sunlight is too strong, a black or silver-gray shade net is placed on the glass roof of the hall and lights are installed on the side to improve the conditions of strong sunlight in the lobby and low illumination at night so as to effectively reflect sunlight, block ultraviolet rays, reduce glare, adjust indoor lighting and temperature, improve the comfort of the indoor environment, and facilitate the preservation of books. The quality of
the reading environment will be guaranteed, which will meet readers' reading needs.

In brief, there are relatively good natural daylighting conditions of the library of Shandong Women's University. The building has met the standards of architectural daylighting and lighting in the architectural design. However, there still exist some problems such as excessive lighting and too strong light in part of reading areas, insufficient illumination in the bookshelf areas, average illumination and illumination uniformity in artificial lighting lower than the national standard value, unsuitable design of light switches, failure to timely repair lighting facilities, and high damage rate of light fixtures, all of which will work against readers’ health and impact the reading environment of the library.

References
[1] Wang Xiang, Measurement and analysis of lighting environment for public reading in north china university of technology. Journal of North China University of Technology, 2005(9):84-89.
[2] Xu Bo, Chai Rui, Research on artifical illuminaition circumstance of library of Three Gorges University. Journal of China Three Gorges University (Natural Sciences), 2007(10):433-434.
[3] Fan Jiadeng, A discussion on the luminous environment in classrooms with elecrical audio-visual aids. Journal of Guizhou Institute of Technology, 1996(6):92-93.
[4] Chen Runping, The study of lighting quality of library based on the fuzzy evaluation method. Bulletin of Science and Technology, 2003 (12):73-78.
[5] Yu Fen, Intelligent lighting control and its application in library. Intelligent Building,2005 (9):56-58.