Research on natural lighting in reading spaces of university libraries in Jinan under the perspective of energy-efficiency

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Abstract. The natural lighting design in the reading spaces of university libraries not only influences physical and mental health of readers but also concerns the energy consumption of the libraries. The scientific and rational design of natural lighting is the key to the design of energy saving for physical environment of the reading space. The paper elaborates the present situation and existed problems of natural lighting in reading spaces of university libraries across Jinan region based on characteristics of light climate of Jinan region and concrete utilization of reading spaces in university libraries, and combining field measurement, survey, research and data analysis of reading spaces in Shandong Women’s University’s library. The paper, under the perspective of energy-efficiency, puts forward proposals to improve natural lighting in the reading spaces of university libraries from five aspects, such as adjustment of interior layout, optimization of outer windows design, employment of the reflector panel, design lighting windows on inner walls and utilization of adjustable sun shading facilities.

1. Introduction
As the main place for college students to read and study, the quality of lighting in the reading space of university library has a great influence on the visual health and learning efficiency of college students. Day lighting design in the reading space mainly includes natural lighting and artificial lighting. Compared with artificial lighting, natural lighting serves an irreplaceable advantage in indoor lighting. First, natural light especially sunlight providing lighting carries radiant heat as well, which can reduce heating energy consumption with the effective use. Secondly, sunlight is conducive to sterilization and disinfection. Therefore, the effective use of natural lighting can not only reduce the visual fatigue of the readers, but also benefit the physical and mental health, improve the efficiency of work and study, and reduce energy consumption to a certain extent [1].

However, there is a common phenomenon in the reading space of libraries: students more tend to draw the curtain when the weather is sunnier than usual, and turn on all the artificial lighting, resulting in greater waste of energy. The natural lighting design of reading space in libraries not only affects the physical and mental health of readers, but also concerns the energy consumption of the libraries. From the angle of building energy efficiency, the scientific and rational design of natural lighting is the key to the design of energy saving for physical environment of the reading space.

2. The characteristics of light climate in Jinan region
The characteristics of light climate in Jinan region directly affect the natural illuminance of library reading space. Location parameters of Jinan (S 116°59′, N 36°40′), of the five light climate zone in China Jinan region belongs to IV area that natural light illumination in the average adds up to 30klx-35klx, illuminance of outdoor natural lighting design is Es 13500lx and the critical one of
outdoor natural light is El 4500lx. Natural light is relatively abundant so, what should be taken into consideration is how to make full use of natural lighting in order to reduce artificial lighting, and energy consumption in designing the library reading space.

3. Illuminance requirements of library reading space

According to the Standard for Lighting Design of Buildings (GB50033-2013), lighting of library reading space and open shelf indoor should not be lower than grade III, in which illumination should be well lightened up meet the accuracy requirements of work. As for side lighting, the standard value of daylight factor is 3%, and the standard value of natural light intensity in reading space is 450lx. See Table 1.

| Lighting levels | Places                      | Side daylighting       | Top daylighting       |
|-----------------|-----------------------------|------------------------|-----------------------|
|                 |                             | Standard values of daylight coefficient (%) | Standard values of indoor natural illuminance (lx) | Standard values of daylight coefficient (%) | Standard values of indoor natural illuminance (lx) |
| III             | reading space open shelf    | 3.0                    | 450                   | 2.0                    | 300                         |
| IV              | collection room             | 2.0                    | 300                   | 1.0                    | 150                         |
| V               | stack room, walkway, staircase, toilet | 1.0              | 150                   | 0.5                    | 75                          |

The standard values of daylight coefficient shown in Table 1 are applicable to the category III light climate zone in China. The standard value of daylight factor is formulated according to the outdoor illuminance values of 15000lx.

4. Survey of the natural lighting in the reading space of the library in Shandong Women’s University

4.1. Overview of the library in Shandong Women’s University

The new library of Shandong Women’s University was built and put into use in November 2009. It was designed by the Architectural Design and Research Institute of Shandong Jianzhu University. It has reached a high level in both design and construction quality. The main lending area is 20.8 thousand square meters, and the building height is 20m with 4 floors. There are nine reading rooms, a periodical reading room, two electronic reading rooms, two self-studying rooms for students, three seminar rooms for group studying and discussing, three independent learning areas, a children's picture book room, a “reading therapy space”, two reading academic report halls, a total of 2127 reading seats, 650 computer information points. With its elegant environment, advanced infrastructure and strong atmosphere, the library is an ideal place for teachers and students to read, study, and work on academic research and cultural exchanges.

The reading space is located on the 1~4 layer planar with its form divided into rectangular and curved, is located in rectangular and curved the area and electronic reading rooms in a rectangular area. This paper mainly focuses on open-shelf reading space as a case study. Open-shelf reading spaces sit toward the south and west with 20~30m bay, 10~15m depth and 4.5m height. The main retaining structure is block with side push-pull window lighting. What are near the windows are some of reading areas which some are in reading spaces and book shelves. Opening hours are 8:30 am to 21:30 from Monday to Sunday continuously and reading spaces, electronic reading room and periodicals reading room are up to 91 hours a week; studying rooms open up to 105 hours. According to the climate, environment of Jinan region and the opening time of the library, it can be seen that the natural lighting time is from 8:00 to 16:00 pm. The author measures on the spot and researches natural lighting design of open-shelf reading spaces as a case in the library of Shandong Women’s University.
4.2. Test of natural lighting and illuminance in reading spaces

The author selected the library reading spaces on Sunny afternoon to measure the indoor light environment in May 2017 with the equipment Digital Lux Meter (AR823). The author has measured three representative illuminance levels in the reading spaces under natural lighting. With the three points in the same line as the deep direction of the classroom, the A point is near the inner wall, the B point in the center, and the C point is near the skylight window (see Figure 1). With the reading tables that are taken as the illuminance measuring reference, the measurement results are shown in Table 2 and Table 3.

**Table 2. Natural lighting illuminance of north-or-south-side-lighting windows (unit: lx)**

| Places                          | A  | B  | C  |
|--------------------------------|----|----|----|
| The Fifth Reading &Borrowing Room | 120 | 420 | 2720 |
| Children’s Picture Books Space   | 290 | 430 | 1970 |
| Tool Books and Foreign Books Lending Room | 90  | 197 | 663  |
| The Back Issues Reading Room     | 107 | 231 | 702  |

**Table 3. Natural lighting illuminance of south-and-west-side-lighting window (unit: lx)**

| Places                          | A  | B  | C  |
|--------------------------------|----|----|----|
| The First Reading &Borrowing Room | 95  | 390 | 2630 |
| The Second Reading &Borrowing Room | 105 | 395 | 2710 |
| The Third Reading &Borrowing Room | 110 | 410 | 2690 |
| The Fourth Reading &Borrowing Room | 130 | 425 | 2760 |
| The Sixth Reading &Borrowing Room | 135 | 430 | 2770 |
| The Periodicals Reading Room     | 210 | 415 | 1950 |

**Figure 1. Sketch map of measuring point in reading spaces**

**Figure 2. Average illumination variation curve under natural lighting in reading spaces**

4.3. Measurement and analysis of natural lighting illuminance in reading spaces.

By arranging the test results, the average illumination variation curve of different observation points is plotted under the natural lighting condition in reading spaces (see Figure 2). The curve shows that the general reading spaces which are under side-lighting conditions have the greater illuminance when closer to the windows, vice versa. Indoor illumination is obviously different, and this situation will be exacerbated with the increase of the depth of the reading spaces.

4.3.1. Under the natural lighting conditions, visual comfort is not ideal. The area with the highest illumination value in the reading room is concentrated near the lighting entrance where the illumination value is over 2600lx, which has exceeded the comfort level of the human body, and will destroy the books and make them aging. From the outside lighting windows to the interior wall, the interior illuminance plummets from 2710lx to about 1051x that the change is very large. Only half of
the reading room area near the light window can satisfy the demand of illumination. The illuminance value of the reading spaces on both-sides of the daylight window is generally higher than that of the reading spaces of the single-lighting window.

4.3.2. There is a rare utilization rate near the lighting entrance. Through the investigation, it is found that the window area of natural illumination is sufficient though, few people read in this area. There is a rare utilization rate near the lighting entrance, and which more than half of the time in natural lighting is covered by shading curtains. Random interviews with students also show that the reading spaces sometimes have too strong or too weak light, and even glare, so that the eyes are very easy to fatigue. The author analyzes the main reason is that the south and west lighting entrances are easy to produce glare affected by sunlight. People feel tired of reading in this environment for a long time, so readers generally do not choose to area that can accept direct sunlight near the window to learn and read, or choose to block the glare of the sunlight with shading curtains.

4.3.3. The area with relatively large depth did not at all reach the required illuminance value. Although lighting entrances are naturally lit, the shelves indoors are high and dense with the large bay and depth of great influence on lighting effects. After the reflection through the shelves, roof and ground, the area with relatively large depth did not at all reach the required illuminance value. Therefore, the area with relatively large depth in the reading spaces needs artificial lighting to supplement whether it is bookshelf or reading area. Under the condition of natural lighting with artificial lighting, the illuminance of all the reading spaces meets the demand with the better illuminance uniformity. However, due to the inadequate use of natural light, employing artificial lighting to meet the demand of indoor illuminance is higher energy consumption.

4.3.4. Lighting system still needs to be improved in its adjustability and interactive intelligent. The research finds that there still a lot of reading spaces make artificial lighting fully open even if the natural lighting has been able to meet the demand of illumination with artificial lighting. In addition, in the absence of readers in the reading spaces, artificial lighting is often not closed in a timely manner, resulting in significant waste of energy.

5. Improvement measures of natural lighting design in reading spaces

5.1. Adjusting the layout of the reading spaces
Books near the lighting entrance are exposed to natural light, which leads to the huge damage on books. What’s more, readers will not stay in the shelf area for a long time so the natural lighting is rarely required. However the reading areas are located inside the reading spaces with obviously insufficient lighting which rely on long-term artificial lighting, resulting in energy waste. Adjusting the layout of the reading spaces, exchanging part of the bookshelf areas with the reading areas, and putting the reading area on the side of the window can not only ensure the books not to be influenced by direct sunlight, but also can make the natural lighting of the reading area more abundant.

5.2. Optimizing the design of outdoor windows
The design of reading outside the windows has a direct impact on the indoor light environment quality. Windows design, in addition to meeting the standard of "proportion of windows to the ground" requirements, should also pay attention to following optimization: (1) to improve the window’s height with side-window lighting to increase the illumination uniformity of the reading spaces and enable natural light to reach the deeper indoor areas. (2) to design the inner wall of the window as a belled-mouth shape to enlarge the lighting range of the reading spaces and reduce the brightness contrast between the window and the inner wall near the room, helping to benefit indoor visual comfort. (3) to select glass material reasonably. In Jinan, double glazing is adopted to meet the need of heat insulation and provide the possibility of passive solar radiation heating in winter [2].
5.3. Using the reflector panel
The reflecting plate can reduce the illumination value near the window and improve that of the far window so the illuminance uniformity of the whole indoor space can be improved, and the comfortable and soft light environment can be realized. The design of reflectors in the South and West windows of the reading spaces can not only increase the natural light depth and save energy, but also play a role of shading in summer. The reflector panel generally uses the high reflection coefficient with easy cleaning and upkeep maintenance of the aluminum plate or aluminum plate outsourcing. The reflector panel divides the window into two with high-side lighting window dually functioning shading and lighting above and scenic window below [3]. As is shown in Figure 3 and the working principle is shown in Figure 4.

![Diagram of reflector panel](image1)

**Figure 3.** Diagram of reflector panel between high-side window and scenic one

![Working principle of reflector panel](image2)

**Figure 4.** The working principle of the reflector panel

In summer, the light with higher height angle can be directly blocked by an outdoor reflector, which functions shading the lower scenic window, reducing indoor heat gain and avoiding potential direct glare. At the same time, the outdoor reflector panel will get the heat-attenuated light reflected into the interior ceiling through the high-side window, improving the interior illumination value from deeper.

In the winter, lower angle light can enter the room to increase the indoor heat required. The light into the interior space reflects the light to the ceiling through the reflector panel to improve illumination value at the far window, indoor reflector panel blocking the direct light downward to avoid potentially direct glare from high-side lighting.

5.4. Designing lighting windows on the inner wall of reading space
Designing the lighting windows on the inner wall between the reading spaces and the corridor can improve inside illumination uniformity in the reading spaces by the light from north or the diffuse one from the opposite reading room. Designing lighting windows on the inner wall of reading spaces can improve the natural lighting level of the reading room, and also can improve the light environment of the corridor in the library, and is beneficial to the natural ventilation of the reading spaces on both sides of the inner corridor in summer. Undoubtedly, it may cause the interference of sight and noise in the reading spaces, which can be solved by strengthening the sealing of the windows and selecting frosted glass [4].

5.5. Adopting the adjustable sun shading in reading spaces
Automatically or manually adjustable shading facilities on the south and east and west walls of the reading spaces can help readers adjust the intensity of natural lighting according to the outdoor natural light illumination and indoor reading demand, natural lighting, improving visual comfort of indoor
light environment.

The shutter with functioning radiation partition can be used. One side of shutter is polished aluminum surface with high reflectivity and low emission while the other side has a light coating with the appropriate absorption rate (especially infrared and far infrared band), which the forms a unidirectional partition through heat radiation in capable of reflecting infrared radiation outdoor in the summer to prevent thermal radiation into the interior to a certain extent, and reflecting far infrared radiation in the winter indoor to achieve insulation. The utility model not only ensures good light regulation performance, but also solves the problem of heat insulation and heat preservation to a certain extent, and at the same time plays the role of decoration and beautification [5].

6. Conclusion

The area of Jinan belongs to class IV of the five light climate division in our country. Combining with the optical characteristics of climate in Jinan and through the field measurement, survey, research and data analysis of the reading spaces of the library in Shandong Women’s University, this paper expounds the present situation and problems of natural lighting of reading spaces of university libraries in Jinan province. In order to make the indoor light environment better and realize the goal of energy saving and emission reduction, this paper combining with the literature research, discusses the measures to improve the natural lighting design from five aspects. It is hoped to provide a useful reference for the design of natural lighting in the reading spaces of university libraries in Jinan. It should be noted that architecture means a whole that architectural design does not consider any single factor in isolation. The improvement measures proposed in this paper for the design of natural lighting reading room of university libraries in Jinan province also need to take into account other factors in the practical application, such as reading spaces acoustic environment, light environment, thermal environment and the appearance of economic performance. Nothing but further analysis and improvement can achieve better results.

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