Energy-efficient Lighting and Biophilic Design Concept to Boost Reading Interest in Social Facilities’ Library

OC Dewi1*, AD Ismoyo2, R Felly3, Aisyah3 and L Yohardi3

1 Lecturer, Department of Architecture, Faculty of Engineering, Universitas Indonesia
2 Lecturer, Architecture, Faculty of Design Technik and Planning, Mercu Buana University, Mercu Buana University
3 Lecturer Assistant, Department of Architecture, Faculty of Engineering, Universitas Indonesia
E-mail: ova.candewi@ui.ac.id

Abstract. Library in public and social facilities such as schools, mosques, churches and training centers has never become the main priority service unless it is intended accordingly. The good thing is, the library in such facilities always merges with other social functions such as special classes, gathering room or even dining room which is an addition to its original function: the reading room. Department of Architecture Universitas Indonesia, together with “Smandel 95 Berbagi Kasih Program” has conducted this community engagement program, funded by the Directorate of Research and Community Engagement Universitas Indonesia, in an orphanage in Jakarta, namely Yayasan Tanjung Barat. The aim of this activity is to increase the occupant’s hobby in reading without renouncing the original activities through an energy-efficient and biophilic concept. Software-based lighting simulation and biophilic intervention concept were conducted to get the optimum result, a part of the design development through multi-discussions with the occupants and observations. Through this study, the energy efficiency from lighting intervention and the biophilic design presence in this library can be increased by 59% and 69% respectively.

1. Introduction
United Nations Educational, Scientific and Cultural Organization (UNESCO) listed Indonesia as the second-lowest rank country in terms of reading interest. By this figure, it means only one individual per 1,000 people who has a high interest in reading [1]. Moreover, the research conducted by the World’s Most Literate Nations Ranked by Central Connecticut State University has ranked Indonesia at the 60th out of 61 countries [2]. These facts have driven the efforts to promote intervention in increasing reading interests through architectural design for the library that is accessed by the young generations who stay in social facilities.

In 2019 the Community Engagement Program of Universitas Indonesia visited Tanjung Barat Orphanage in South Jakarta in cooperation with Smandel 95 Berbagi Kasih Program. These activities combined multiple focus group discussions, design and crowdfunding to implement the result. In this study, the use of biophilic design integrated with sufficient lighting as a form of energy efficiency is proposed to be the main concept of intervention. This paper has finalized the design process. The aim of the design is to boost the reading interests by improving the room quality specifically through energy-efficient lighting and biophilic concept.
2. Literature review

2.1 Lighting towards energy efficiency and reading interest

Over a quarter of a total energy use in small commercial buildings in U.S. goes towards lighting, thus focusing on lighting efficiency can save a large amount of energy [3]. And according to questionnaires distributed by Xuan and Li (2011) to 100 public libraries and university libraries in China, libraries built before mid-1990s which have window lighting spend less than 40 kWh/m²/year; while newer libraries which have poor natural lighting and more artificial lighting spend more than 70 kWh/m²/year [4]. Therefore, using energy-efficient lighting can help reduce energy consumption in commercial buildings, especially in places such as libraries where lighting is essential. Natural lighting is recommended as the source of lighting during the day since it can reduce energy consumption coming from artificial lighting. Furthermore, the full spectrum of sunlight provides the richest spectral of visible light to be used by the eyes for reading. Research shows that reading is the most visually stressful task for children [5]. Stress causes a contracted visual field in the eye that can lead to a decrease in information processing and learning ability [5]. Providing natural lighting can reduce eye stress, therefore increase the children’s learning process. Sunlight is also a source of vitamin D, which contributes in decreasing dental decay rate in children [5,6]. A daylight factor (DF) is the ratio of the indoor daylight level to the outdoor daylight level [7]. The minimum DF for libraries is 2, and the average is 5 [8].

Table 1. The Difference in Energy Consumption of Fluorescent Lamp and LED Lamp [4]

| Light Distribution | Fluorescent Lamp | LED Lamp |
|--------------------|-----------------|----------|
| Type               | 2 x 28 W        | 20 x 1 W |
| Power (W)          | 56              | 20       |
| Number             | 100             | 100      |
| 8 Hours (kWh)      | 44.8            | 16       |
| 1 Year (kWh)       | 16,532          | 5,840    |

Although natural lighting is the best source of lighting, there is a need for artificial lighting to illuminate the room during night time. LED lamps are the best choice for artificial lighting because of the following reasons. First, LED lamp exudes flicker and weak glare, thereby protecting vision health [9]. Second, there are only visible light (wavelength: 0.38 µm - 0.78 µm) [10] in LED spectrum (wavelength: 0.40 µm - 0.75 µm) [11,12], so neither heat nor radiation from UV light and infrared can penetrate the books' surface, thus ensuring the durability of the books. Third, LED lamps can last for 25,000 - 50,000 hours; while compact fluorescent lamps (CFL) only last for 6,000 – 10,000 hours [13,14]. Fourth, different angles light distributions from LED lamps, as shown in table 1, improve utilization efficiency and make reading more comfortable. Lastly, LED lamps can save 10512 kWh/year, which equals to 64.2%, as seen in Table 1. In addition, LED lighting can be dimmed according to different environment using infrared sensor control system, which can save another 30%-40% energy [4].

In a library, lighting is not only used to read books, but also to search for them. In Calgary, Canada, the strip lightings are illuminating the book spines to draw the patrons’ eyes to the books’ titles on the shelf; not only for them to spot, but also to make the books more attractive [15]. The lighting level on the book stack face should be minimum 65 lux at a height of 30 cm, and maximum 377 lux at any height [16]. And the standard lighting level for the libraries’ general area is 500 lux [8]. There are various approaches of lighting scheme for book stacks and reading areas, as shown in Table 2 and 3.
### Table 2. Stack Lighting Scheme in a Library [16]

| Scheme               | Description                                                                 | Usage                           | Advantages                                                                 | Disadvantages                                                                |
|----------------------|------------------------------------------------------------------------------|---------------------------------|---------------------------------------------------------------------------|------------------------------------------------------------------------------|
| Parallel Scheme      | A single row of one-lamp linear fluorescent fixtures centered above each aisle | High ceiling room               | Have the lowest energy use                                               | Difficult without modifying the ceiling grid                                  |
| Perpendicular Scheme | Rows of two-lamp linear fluorescent fixtures running at right angles to the stacks, positioned in the center | Above compact shelving where there are no fixed aisles | Easily coordinated with the ceiling grid, Have the lowest-cost solution | Each fixture has two lamps, so it may not have the lowest energy use          |
| Indirect Scheme      | Lights on top of the stacks or suspended from the ceiling                    | When the ceiling is white and enough light reaches the bottom shelf | All of the light is reflected off the ceiling, so the illumination on the stacks is very soft, and the entire range of stacks appears to have a pleasant glow | The energy use is higher than the parallel or perpendicular schemes          |
| Hybrid Scheme        | A combination of perpendicular and indirect schemes, with rows of direct-indirect fixtures suspended perpendicular to the stacks | When the ceiling is higher than 3 m | Have a moderate cost and reasonable energy use                           | Outward-facing shelves are difficult to light because the plastic protective folders on the magazines reflect any overhead lighting, which obscures the covers |

### Table 3. Reading Area Lighting Scheme in a Library [16]

| Scheme        | Description                                                                 | Usage                           |
|---------------|------------------------------------------------------------------------------|---------------------------------|
| Indirect Lighting | Uses up lights to illuminate a light color ceiling                          | For both paper-based and computer tasks in rooms, where the ceiling height is at |
| Direct Lighting    | Uses down lights to illuminate the reading tables                           | For reading tables              |
2.2 Biophilic design towards energy efficiency and increased reading interest

The biophilic design a design concept and a standard that aims to make active use of various elements of nature and its changes in architectural environment design [17]. Some forms of this design which contribute to energy efficiency are natural ventilation that allows light, thermal and airflow availability, and also the presence of water and plantation [18].

The natural ventilation can reduce building energy consumption resulted from heating and cooling loads, especially in tropical countries where a building’s energy consumption mainly comes from the latter. An electronic library at Pibulsongkram Rajabhat University consumes 81.49% of its energy for the air conditioning system [19]. The science center building at Suan Sunandha Rajabhat University also spent 87% of its energy consumption for air conditioning [20].

The natural and transparent light, especially the one coming from the sun, can increase positive emotions in people’s minds and cause creativity [21]. Light is always associated with transparency in architecture. Providing adequate sunlight during the day can increase the accuracy and concentration of senses, eye health and vision power [22].

Placing water features near the building’s ventilation can cool the air which flows through it, helping to reduce the cooling load of the building. The natural fluctuations of visual stimuli created by water can reduce stress, increase relaxation, decrease heart rate and blood pressure, and improve concentration and memory [23].

The presence of indoor air purifying plants can help purify indoor air pollution [24,25], easing the work of air purifiers and the one coming from the air conditioner. Such indoor plants can include garden mum (*Chrysanthemum morifolium*), spider plant (*Chlorophytum Comosum “Vittatum”*), dracanea (*Dracanea spp.*), ficus (*Ficus benjamina*), peace lily (*Spathiphyllum sp.*), boston fern (*Nephrolepis exaltata v. Bostoniensis*), snake plant (*Sansevieria trifasciata*), bamboo palm (*Chamaedorea seifritzii*), aloe vera (*Aloe vera*), chinese evergreen (*Aglaonema modestum*), english ivy (*Hedera helix*), and gerbera daisy (*Gerbera jamesonii*) [24,26]. Their presence can also reduce irritation to eyes, cough, and congestion caused by SBS (sick building syndrome); lower the environmental stress, boredom, and tiresome; and increase comfort and focus [18,26,27].

3. Methods

3.1 The case studies

The study took place in Tanjung Barat orphanage in South Jakarta. The library in this facility is also functioned as a dining and social gathering room. This study is aimed to determine the increased energy efficiency from lighting and biophilic design intervention. The first step of the study was done by observing the existing’s biophilic aspects and measuring the illuminance level of the existing library.

3.2 Lighting efficiency

The illuminance level of the library was measured directly on the site at 09.00 am in October 2019. The illuminance level was measured while the windows are opened and the lamps turned on. Subsequent to the illuminance level measurement of the existing library, software-based lighting simulation was applied to see the lighting performance of the existing library and after the intervention. DiaLux software is applied for the simulation as it is familiar with lighting designers and is supported...
by many lighting industries. The lighting performance and efficiency were evaluated based on the ratio of illuminance level and total luminous flux used in the library. The total luminous flux is measured in lumen, while the illuminance level measured in lumen per meter square (lux). As the illuminance level is measured only on the visual task area, this study can determine the efficiency of the artificial lighting in the library. The lighting intervention for the library was designed based on the visual task areas and the biophilic design pattern. The lighting intervention has the same luminous efficacy as the existing lighting. The measured illuminance level is a combination of natural and artificial lighting.

3.3 Biophilic design
In this study, the scoring of existing and intervening biophilic design is evaluated based on 14 Patterns of Biophilic Design [28]. There are 14 patterns that divided into three categories, namely nature in space, natural analogs, and nature of the space. The first step is observing the presence of the existing biophilic design in the room to see its score using the Index Value Table of Biophilic Design [29]. After obtaining the existing score, the next step is analyzing what patterns that are not fulfilled in the existing room, then classify it to the categories of the intervention patterns. The observation result would be the foundation to apply the biophilic design intervention patterns. The categories of the intervention patterns that applied in the room can increase the biophilic design score.

4. Result and discussion
4.1 Lighting
4.1.1 Lighting design intervention
The lighting intervention in the library was designed based on the visual task areas and the biophilic design pattern. In terms of efficiency, artificial lighting was used to highlight only the visual task area such as reading tables and the bookshelves. The non-visual task areas were not specifically highlighted by artificial lighting. The LED downlight is used to highlight the bookshelf while the LED stripe light highlighted the reading table (Figure 1). The circulation area was not highlighted by any lamps. The biophilic design pattern is applied by using indirect lighting and artificial lighting with similar Colour Rendering Index (CRI) to the sun circadian system.

Figure 1 Existing lighting layout of the library and after the intervention (a) existing lighting design, (b) lighting design after intervention
The lighting design intervention of the library has a greater fixture amount than the existing lighting, but the number of lumens of each lamp is lower. It is aimed to improve the illumination level in certain areas (visual task areas). Both the existing lighting and the lighting intervention have the same luminous efficacy. Figure 1 shows the existing and intervention lighting designs of the library, and how the lighting design intervention fitted to the biophilic design pattern and visual task area.

4.1.2. Lighting calculation
Software simulations were applied to both existing lighting design and lighting design intervention of the library. Figure 2 shows the perspective results of DiaLux software simulation.

The site measurement of the existing library shows that the illuminance level of the library is 50 lux and considered to be very low. The simulation software shows a much higher illuminance level of the existing library. The illuminance level difference between site measurement and software simulation calculation on the existing library indicates the decrease of lamps performance. Table 4 shows the illuminance level of the existing library and after the intervention resulted from the site measurement and software simulation.

| Areas                        | Existing Site measurement | Existing Software simulation | Intervention (Software simulation) |
|------------------------------|---------------------------|-----------------------------|-----------------------------------|
| Reading table (visual task areas) | 50                        | 554                         | 884                               |
| Floor                        | 32                        | 461                         | 242                               |

The software simulation of lighting intervention shows a higher illuminance level (59%) on the reading table area, while the floor area shows a lower illuminance level (Table 4). This result shows that the illuminance level of the lighting design intervention on the preferred area is higher.

4.2 Biophilic design intervention
Based on the existing survey, it is found that the biophilic design score is 55 points. Existing observation showed that there are ten ways to apply the interventions, namely adding any kind of interior plants, adding aromatherapy, changing the fixed windows to flexible windows, adding eco-friendly air conditioner, adding aquarium and fish, designing artificial lighting with circadian system, adding bookshelf with the design that adapted from tree and root shape, adding wallpaper with static patterns, and designing the safety system to take the book in the high position racks (Table 5). This intervention steps changed the score from the existing 55 points (before) to 93 points (after), which is increasing 69% of the biophilic design presence. The kind of interior plants that applied in the intervention were air-purifying plants and oxygen plants, such as Sansevieria Trifasciata Prain, Chrysanthemum, Chlorophytum comosum, Dracaena, Ficus Benjamina, Spathiphyllum ‘Mauna Loa’, Nephrolepis Exaltata, and Aloe Barbadensis plants (Figure 3). It is aimed to increase the oxygen capacity in the room and make the room fresher. It will boost the users’ interest in reading as they will feel more relax.
| No. | Biophilic Design Pattern                  | Intervention steps                                      | Total Score | Existing Score | After the Intervention Score |
|-----|------------------------------------------|--------------------------------------------------------|-------------|----------------|------------------------------|
|     | **Nature in space**                      |                                                        |             |                |                              |
| 1.  | Visual connection with nature            | Adding any kind of interior plants                     | 11          | 9              | 2                            |
| 2.  | Non-visual connection with nature        | Adding Aromatherapy                                    | 7           | 5              | 2                            |
| 3.  | Non-rhythmic sensory stimuli             | Existing                                               | 3           | 3              | 0                            |
| 4.  | Thermal & Airflow Variability           | There is no air velocity, so fixed window is changed to flexible window | 11          | 6              | 5                            |
|     |                                          | Adding Eco-Friendly Air Conditioner (AC)                |             |                |                              |
| 5.  | Presence of water                        | Adding aquarium and fish                               | 8           | 0              | 8                            |
| 6.  | Dynamic & diffuse light                  | Designing artificial lighting with the circadian system | 12          | 5              | 7                            |
| 7.  | Connection with natural system           | Adding any kind of interior plants                     | 8           | 7              | 1                            |
|     | **Natural analogs**                      |                                                        |             |                |                              |
| 8.  | Biomorphic forms & patterns              | Adding bookshelf with a design adapted from tree and root shape | 7           | 0              | 7                            |
| 9.  | Material connection with nature          | Adding bookshelf with a design adapted from tree and root shape | 12          | 11             | 1                            |
| 10. | Complexity & order                      | Adding wallpaper with static pattern, e.g.: sun flower patterns | 2           | 0              | 2                            |
|     | **Nature of the space**                  |                                                        |             |                |                              |
| 11. | Prospect                                 | It is not applied as it is a structural intervention   | 6           | 4              | 0                            |
| 12. | Refugee                                  | It is not applied as it is a structural intervention   | 5           | 0              | 0                            |
| 13. | Mystery                                 | Adding any kind of interior plants                     | 6           | 5              | 1                            |
| 14. | Risk/Peril                               | Designing the safety system to put the books in high position racks, e.g. stairs | 2           | 0              | 2                            |
|     | **Total**                                |                                                        | **100**     | **55**         | **38**                       |

*Figure. 3* Perspective design after applying the biophilic design’s interventions
5. Conclusion
The intervention concept that will be applied in the Tanjung Barat Orphanage’s library is proven to have better lighting efficiency and greater biophilic design presence. These improvements show that not only the occupant’s interests in reading will improve through the biophilic design presence, but also the energy-efficient through the lighting interventions. Overall, the design process calculates the energy efficiency from lighting intervention can be increased by 59%, whereas the biophilic design presence can be increased by 69%. The design implementation is expected to finish at the beginning of the year 2020. Currently, both Universitas Indonesia and Smandel 95 Berbagi Kasih are running a crowdfunding program to meet the budget requirement. For the next step, the same action will be carried out in Yayasan Cipta Mandiri in Bogor City, West Java and followed by other social facilities.

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