Design Considerations of Side lighting, Top lighting and Atria in Laboratory Buildings

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Abstract— **Since the nineteenth century, the study of daylighting in laboratory buildings has been a topic of interest. Excellent laboratory design should provide a view outside as well as using daylight as the light source compared to artificial lighting providing a cost-efficient, pleasant and healthy environment. Nowadays, the need to have an efficient daylit design of laboratory buildings is necessary. Hence, this study aims to deter a guideline design consideration for daylighting in laboratory buildings. This study performs a literature review to understand the importance of daylighting practices for laboratory buildings prior to the selection of several daylighting case studies. By taking laboratory buildings as the case studies, this study measures the integration and application of daylighting in laboratory buildings on their respective daylighting approaches. There are three daylighting criteria selected in the case studies which are; (1) Side lighting, (2) Top lighting and (3) Atria. This study finds that the best daylighting approach in laboratory buildings is by side lighting at the north and south facing building façades. The most effective daylighting is side lighting which has the best method of providing daylight inside laboratory buildings.This electronic document is a "live" template and already defines the components of your paper [title, text, heads, etc.] in its style sheet.**

Keywords—laboratory; side lighting; top lighting; atria

I. INTRODUCTION

In a research done by Stephen [1], she concluded that laboratory building is normally monotonous and is lacking in term of a place for architecture that transports us beyond the mundane. The manipulation of light, space and volume is normally set aside to fulfil the demand of the programs for various types of research. Based on the history of laboratory buildings, the activities that take place in a laboratory building outweigh the role of architecture and resulting in only supporting and responding to the activities. The success to cater for specifies programmatic demands of the inhabitants is normally contributing to the successfulness of the projects. Moreover, as the most prominent elements of the space are laboratories and mechanical systems, designing a laboratory building always put function first as to meet the building codes and infinite regulations set by the laboratories' programs and activities.

The problem in designing laboratory building, besides the abundant of regulations and codes as well as the demanding limitations of the program, is how architects can play a role in designing inspirational architecture for the future and incorporate architectural poetry into this function-based building typology. Laboratory buildings are also consuming remarkably significant natural resources. Based on the previous study by Dahan [2], laboratory buildings are said to consume 5 to 10 times more energy than office buildings per square foot. Not only that, as to compare with similarly sized commercial or institutional structures, laboratory buildings that equipped with clean rooms and laboratories with large process loads use 100 times more energy per square foot. Therefore, it is imperative to foster innovation and enhance the performance of scientist and other researchers in designing laboratory buildings. One way to tackle this issue is by making good use of natural light, or daylighting in designing and building laboratory buildings. Daylighting can be used to combat the problem of consuming the natural resources [3]. As laboratory buildings are all about discovery, daylighting helps to stimulate creativity and innovation by providing effective interior work environments [4].

Romm and Browning [5] concluded that the increase of productivity and performance of their inhabitants are related to the exposure of daylighting in the buildings. As a result of providing natural light as well as views to the outside, the productivity of the inhabitant's increases of even 1%. Moreover, to retain top scientists and other key research personnel, it is a good measure to provide access to natural light and views towards the outdoors in offices and laboratories. The objectives of the study are to understand the importance of daylighting practices for laboratory buildings. The first objective is to collect on daylighting strategies through international literature. Two main sections of the literature review are; (1) understanding the technology and (2) design considerations for laboratory buildings. The second objective is to a discussion on the case studies for laboratories buildings to determine how daylighting are being implemented as well as to assess the integration and application of daylighting in the laboratory buildings.

II. LITERATURE REVIEWS

The study has two sections: (1) Understanding the technology and (2) Design consideration for laboratory buildings.

1. Understanding the Technology

Daylighting is defined by the controlled entry of natural light into a building. To save energy, the occupants can use daylighting to dim or turn off a building's artificial lighting. There are many ways that daylighting can be provided into a space such as windows, skylight, roof monitors, clerestories, sawtooth roofs or light-pipe systems. To save energy, daylighting should be integrated into the building's overall design and interior spaces as well as into the electrical lighting and mechanical systems. Window installation in the building provides a considerable amount of daylighting in the indoor room.

However, the number of windows does not necessarily mean an increase in the amount of daylight. Consideration in term of location and size of windows need to be taken to ensure a relatively even amount of daylight in the building's interior. Besides, a review should also be done to avoid the problem of heat and glare as well as minimizing the penetration of direct sunlight into work areas.

Despite information of daylighting in commercial buildings is widely available, architects face different issues on daylighting systems for laboratory buildings. Designing laboratory buildings has significant lighting differences from commercial buildings. In laboratory areas, the interstitial spaces between floors as well as the complexity of electrical and mechanical equipment and systems in laboratory buildings. As to compare with commercial buildings, laboratory buildings require large interstitial spaces above the ceiling to cater for mechanical and electrical equipment as well as ductwork. Although laboratory buildings have the added floor-to-floor height, the large interstitial spaces provide a unique challenge, and as a result, daylight cannot reach farther in the space.

Laboratory buildings requirement for lighting and daylighting can vary widely. For some laboratories, daylighting might not be desirable, but access to view is a must while in some others, space may require more ambient lighting due to task lighting being a problem for the scientists. In some cases, designing for daylighting in the laboratories portion of the buildings can be seen as a challenge, and the architects opt to specify daylighting for public areas and offices, instead. The principle of the design is because laboratories require more energy for ventilation than for lighting, but public areas and offices usually are account for 37% of energy consumption of the overall buildings [6]. Using daylighting in these spaces can reduce the lighting load significantly.

Integration of daylighting into the design of laboratory buildings can be said as more challenging as to compare with other building typology because of the complexity of electrical, mechanical and plumbing systems in laboratory buildings. Watch [6] concluded in his book that 50% of a laboratory's construction budget is allocated for electrical, mechanical and plumbing systems while in an office building, these systems typically represent up to 25%.

These complexities in providing an efficient daylighting in laboratory buildings might be put off by some architects. Nevertheless, if proper measures are taken into considerations, daylighting in laboratory buildings can have a new standard practice to resolves these issues. Hayter [7] noted there are three sources of daylighting which are;

(1) Exterior light reflected into a building from the pavement, ground, adjacent buildings as well as other objects,

(2) Direct sunlight which usually is blocked from penetrating the inside space to avoid a problem of glare, heat gain and ultraviolet degradation issues and

(3) Internal lighting reflected from ceilings, walls and other interior surfaces.

2. Design Consideration for Laboratory Buildings

Based on the book entitled "Research Laboratories" by Daniel Watch [6], for this type of typology to allow daylight to penetrate into the laboratory spaces, design considerations are essential for laboratory buildings. There are five design considerations for laboratory buildings to make daylight as a necessary source of lighting in the laboratories which are as follows:

a. Building Footprint and Mass

As to compare with the east and west sides, it is considered more straightforward to daylight the north and south sides of the laboratory buildings by specifying a long and narrow footprint along the axis of east and west. Due to the sun angles on the east and west, glazing should be minimal especially on the west side because of the difficulty of shading.

b. Window Shading

Consideration of window shading on the east and west façade to protect from direct sunlight as a well-designed space is necessary to capture indirect light from the sun. There are many options to cater for the shading issues which includes louvres, self-shading windows in deep exterior wall sections, vertical fins, horizontal overhangs as well as light shelves [8]. Integration of horizontal shading devices into the building's structure works well on the south façade. Form an architectural standpoint, the building façade of the laboratory buildings will look different from north and south façade. However, for east and west facing façade, recommendation for vertical baffles, wing walls and fins should be considered if windows placing are along the east and west façade.

c. Interior Colours, Ceiling Height and Window Height

To distribute daylighting evenly and most efficiently, consideration of light-colored interior spaces, tall ceiling as well as high window need to be done by the architects. It is imperative to provide natural light and access to the view outside for scientists and other research personnel in the interior space. For this idea to take place, designing laboratories by specifying horizontal windows above eye level is crucial if the laboratories' location is along the exterior walls. Moreover, the windows' placement is critical in adjacent to the walls across from them. Also, for the occupants to have unobstructed windows, a strip of glazing above shades need to be provided to avoid window blockage.

d. Integration with Electric Lighting

Integration of daylighting design with electrical lighting is necessary working together as one system in determining the best control strategy for the light which includes photo sensor and occupancy control, selecting the proper task and ambient lights as well as defining zones for electric lights. Moreover, it is an important consideration to ensure the lighting control system works as commissioned.

e. Quantity and Quality of Light

To achieve the highest level of efficiency in daylighting in laboratory buildings, in term of quality and quantity of light for a given task, consultants must use computer modelling tools because daylighting design signifies both an art and a science. These computer tools would help to provide information regarding the size of window openings, the selection of glazing properties, the integration between daylighting and electric lights as well as the specification of the lighting control system. In any given space, the quality of light is important to cater for the uniformity of light levels, veiling reflections as well as control of glare. Uniformity of light is the primary element of daylighting in the laboratory buildings as the variation of light levels can cause eyestrain as well as unnecessary use of electric lights and shades. In order to provide more uniform light, the space must have low contract rations as well as windows on to sides to cater for an even brightness space. A well-daylight space needs to avoid the problem of glare and veiling reflections as they can cause eyestrain as well as obstructing the ability to see details. Hence, to avoid these issues, the architects must minimise direct sunlight on visual tasks.

III. Methodology

To ensure an appropriate and correct outcome in conducting this study, the establishment of a proper research method is necessary while setting up for this study. Brikci [9] argued that the research must be driven by three objectives which include; (1) to discover a new insight of particu issues, (2) to test a hypothesis and (3) to uncover a character and quality of groups or typology accurately. According to Yin [10], a case study can be defined as an empirical enquiry that analyses and investigates the contemporary phenomenon within a real-world context in depth. Therefore, this study uses qualitative research as the research methodology for this study. The process of each scenario listed before is studied accordingly to supply the data and information into the comparative studies between the daylighting schemes in laboratory buildings through the case studies.

The study contains two phases of the research methodology. The first phase consisted of literature search and review which was carried out through international journals. From the literature review, daylighting technology and the design considerations for laboratory buildings are crucial for the purpose of conducting the case studies. For the second phase of the study, data was collected from books, journals, and internet information to understand the quality of daylighting scheme in each laboratory buildings. Analysis of each case studies was under three daylighting approaches which are side lighting, top lighting and atria to facilitate daylighting into the laboratory spaces in the buildings.

IV. Result of Analysis

Side lighting, top lighting and atria are the most common types of daylighting. In this research, there are 3 three main daylighting approaches for the case studies analysed, which are; (1) Side lighting, (2) Top lighting and (3) Atria.

1. Side Lighting

For side lighting, daylight penetrates the interior space through windows below ceiling height and this technique of daylighting is typical in laboratory buildings. To achieve uniformity in daylighting, horizontal strip windows are often used to compare with individual windows. Moreover, to cater for a greater depth of penetration of daylight into the interior space, window openings should be located higher on the wall. When designing side lighting, it is also recommended to build separate windows for a view out the building and daylighting.

Based on the research done by O'Connor et al. [11], to achieve the most efficiency for side lighting, the distance that daylight can penetrate into the interior space should be ranging from 1.5 to 2 times the distance from the top of the window to the floor. Figure 2 shows the illustration of the rule of thumb for daylighting using side lighting that includes a view window, a light shelf and a clerestory window. He also concluded that by adding the light-shelf, it would help the light to bounce of the ceiling and distribute the illumination better as well as reducing glare from direct sunlight. Exterior light shelves perform better than interior light shelves providing more shades and less glare.

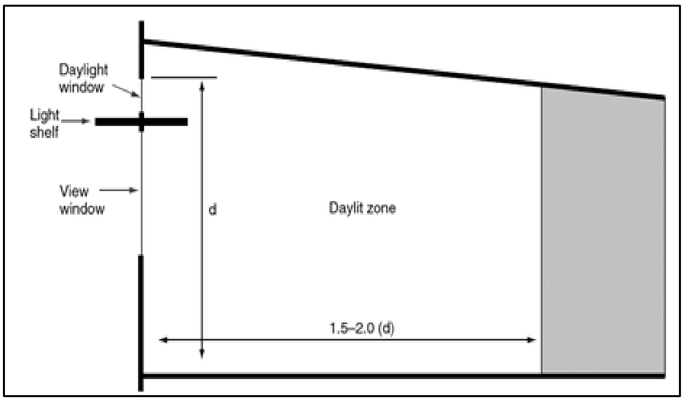

Fig. 1 shows a cross-section of a room to illustrate a rule of thumb for daylighting (Source: O'Connor et al. [11]).

Figure 1 also illustrates the ceiling tilted downwards away from the windows. The sloping ceiling helps to diffuse the daylight uniformly to improve the quality of light in the interior space as a comparison with the flat ceiling which would make the interior space near the center darker. As mention before, as these windows cater for different uses, the glass window above the light shelf has a higher visible transmittance than the view window. The orientation of the buildings affects the daylighting performances, ideally, to control glare and heat gain [12]. The windows that are facing south should be with external light shelves, horizontal overhangs or internal and external light shelves. However, the issue is different for north-facing windows as do not require any shading. For building façade that is facing east and west, the existence of windows for daylighting is not recommended, especially on the west side because it is difficult to control glare and heat gain. However, if there is a need to design windows on both east and west sides of the buildings for daylighting, it is recommended to provide with recessed windows and external vertical fins.

Figure 2 shows the example of laboratory building that uses side lighting as the daylighting technique and two prions for placing windows high in the space. Building 50 at the National Institute of Health Complex in Bethesda, Maryland is one of the examples of using sizeable floor-to-floor dimension as its advantage to provide daylighting in the multi-storey laboratory building as shown in Figure 2. Due to its large dimension of floor-to-floor, the windows are installed with the height of 5.4 metres to allow the workstations and the lab bench areas to receive an ample amount of daylight. For each storey, at both ends of the windowed wall, there are corner-enclosed offices with the height of 2.4 metres. These offices are designed with glass wall to ensure that they do not obstruct the daylighting to the laboratory areas. The layout was designed to provide a quality daylighting in the laboratory areas as well as adequate workstations with windows windows [13].

Architecturally, the design of the building showcases they key sustainable feature in term of capturing a significant amount of daylighting to reduce the usage of artificial lighting. By ending the interstitial level approximately 3.5 metres from the windowed-wall as well as using a curve ceiling, proved to be an innovative method to capture daylighting into the laboratories. The architect took advantage of the sizeable floor-to-floor height as well as the 5.4 metres high window to allow a significant amount of penetration of daylighting into the laboratory areas which are 9 metres away from the windows [13].

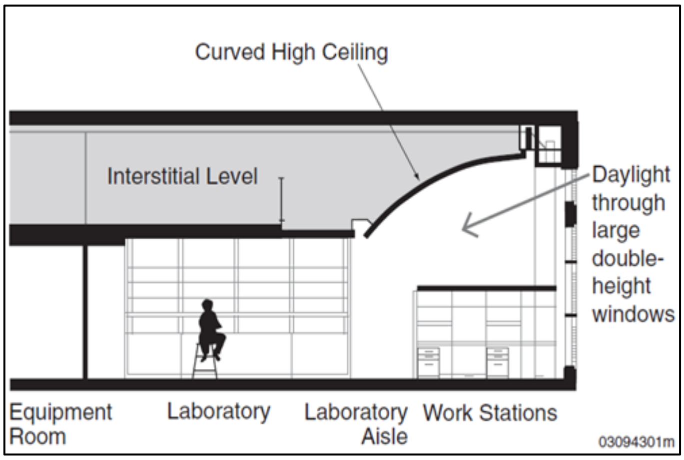

Fig. 2 shows the cross-section and photograph of the laboratory of Building 50 at the National Institutes of Health (NIH) complex (Source: U.S. Environmental Protection Agency [13])

2. Top Lighting

For top lighting, to provide daylighting into the interior space, vertical windows are located above the ceiling line. In top lighting approach, if overheating can be avoided, windows can also be configured horizontally by using specially designed horizontal skylights in which the location is in deep window wells. When windows are not suitable for the function of the perimeter walls and side lighting is not able to accommodate in the interior space, top lighting can be the effective daylighting approach for the building. Not only that, if there are security concerns or lighting criteria for side lighting is inappropriate, architects can always opt to use top lighting to provide daylight into the laboratory areas.

Figure 3 shows the daylighting approach in a classroom building in the Centre for Technology and Learning Media in Golden, Colorado, which is using top lighting to provide the inside spaces with daylight. As daylight apertures can face north and south, the usage of deep window wells can help to reflect and diffuse light inside the area. For this building, to prevent glare that is caused by exposing to direct sunlight on visual tasks, the architects incorporated a perforated metal ceiling to help diffuse the light evenly in the interior spaces. A cross-section of the Centre for Technology and Learning Media shows the vertical windows above the ceiling line to cater for the need of daylighting inside the classroom.

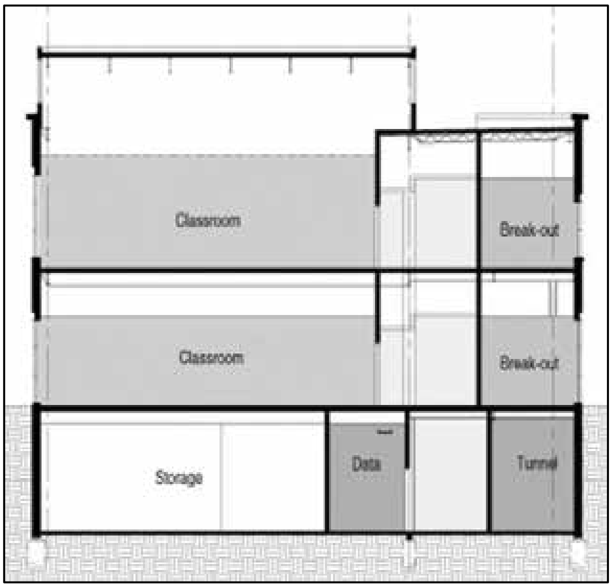

Fig. 3 shows the section through classroom block of the Centre for Technology and Learning Media building (Source: U.S. Environmental Protection Agency [13]).

3. Atria

To increase the amount of natural light received in a building, adding an atrium is proved to be an effective method to provide daylighting in a building. Typically, an atrium located in the central area of the building in one or more stories height has with either side lighting or top lighting. Pharmacia's Building Q, which is a pharmaceutical research laboratory in Skokie, Illinois, is one of the examples of laboratory buildings that uses atrium for the purpose of providing daylighting into the interior spaces.

As providing natural light into the building is considered as one of the essential environmental strategies, the building has two skylight atria (Figure 4). To help distribute the illumination downward and even out the light, the atria use skylights equipped with a passive solar optical system to eliminate hot spots in the building. Besides, the glazing of the skylights has the same properties as the building's perimeter windows which used spectrally selective Low-E glazing.

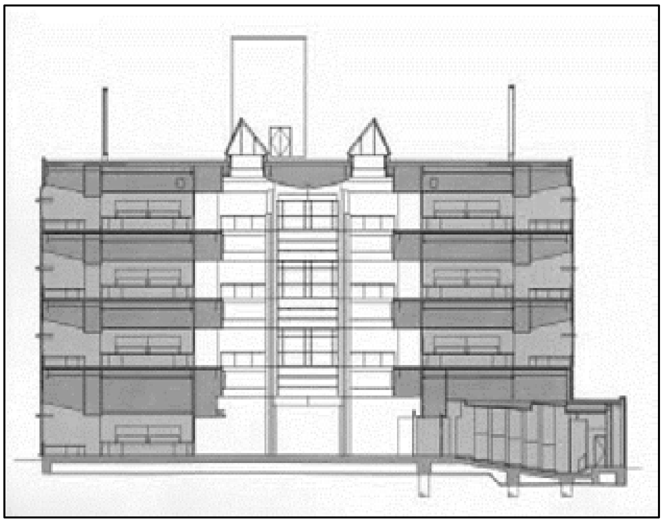

Fig. 4 shows the building section showing the interior atria, which provide daylighting (Source: Flad & Associates, Architect).

The distance between the atria and the exterior wall of the building is 13 metres. The workstations' location is along the perimeter of the building, and the laboratory areas are mostly not separated. However, in some laboratory where separation is necessary, the separation is done by using glazed partitions to provide the spaces with invisible physical barriers. Taking advantage of the daylight, the architects applying daylighting by designing the laboratories which are located next to the atria, with glass wall (Figure 4). It is an essential part of the design as the glass wall allows natural light to penetrate the entire building.

As the interior of the building receives a large amount of daylight through the atria and the windows along the perimeter wall, the energy consumption for artificial lighting has a reduction significantly. Not only that, the productivity of the employees and the visual levels have improved as the result of using daylighting. Moreover, as the building is integrating light sensors in the laboratories when the laboratories are not in use, the sensors turn off the artificial lights, thus, reducing the energy load to bright the building.

V. DISCUSSION

The result of the analysis in the case studies is in Table 1 which lists the different types of daylighting approaches and the window systems used by each case studies. It also gives information on their ability to protect against glare, if they allow views to the outside, can guide light into the depth of a room, can provide homogeneous illumination as well as can save energy use by artificial lighting.

Table 1: The summary of daylighting approaches (abbreviations in table: Y=Yes, N=No).

Daylighting Approach	**Building**	**Types of Windows**	**Criteria for the Choice of Elements**				
			Glare Protection	View Outside	Lighting Guiding into Depth of Room	Homogeneous Illumination	Saving of Energy for Artificial Lighting
Side Lighting	National Institute of Health Complex	Double-height vertical windows	**Y**	**Y**	**Y**	**Y**	**Y**
Top Lighting	Centre for Technology and Learning Media	Vertical windows above ceiling line	**Y**	**N**	**N**	**N**	**Y**
Atria	Pharmacia's Building Q	Skylight from atria	**Y**	**N**	**N**	**N**	**Y**

Based on the case studies done in the laboratory buildings, the best daylighting approach in laboratory buildings is by side lighting. Side lighting is the most effective daylighting type as it is the most straightforward method for providing daylight into laboratory buildings. However, this type is only suitable to be used on both the north and south facing façade because it is difficult to control glare and heat gain from the eastern and western sun. The analysis proves that side lighting is able to illuminate the interior space evenly and diffuse the light into the laboratory areas uniformly. However, to achieve an even brightness in term of illuminance in laboratory buildings, the architects must provide side lighting from both sides of the laboratory areas. Side lighting is also proven to allow natural light to penetrate farther back into the interior space as to compare to other lighting approaches.

The windows for side lighting should have a separation into two functions based on their height which is to cater for the views outside (using eye-level window) as well as for the penetration of daylight (using high-level window). Furthermore, by separating these windows, this would allow for the existence of light shelves in between the windows. These light shelves would help to distribute the illumination better and reduces glare, because light shelves help the light to bounce off the ceiling, thus creating a brighter space in the laboratory areas.

VI. Conclusion

Daylighting is one of the principal vital factors in designing sustainable laboratory buildings as it helps to save energy, reduces costs that are associated with electric lighting as well as enhances productivity. Daylighting should be one of the essential elements of a laboratory building. The best time to address the need of daylighting in this type of typology is during the goal-setting process because measurable goals can be specified when defined. To design a successful daylighting strategy should consider elements which are the building's external image, form, site as well as its electrical and mechanical systems. Therefore, setting a goal for daylighting is essential in an integrated design process.

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