2026 ASEE ANNUAL CONFERENCE June 21–24, 2026 | Charlotte Convention Center, NC
Host Sponsor UNC Charlotte
Paper ID #52343

Application of the Daylighting Laboratory in Educating architects and Engineers.

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Application of the Daylighting Laboratory in Educating architects and Engineers

Abstract: This article is currently a work in progress (WIP). This paper presents an overview of the daylighting laboratory constructed in 2006 through a National Science Foundation (NSF) grant obtained by the second author at the School of Architecture (SOA) at Oklahoma State University (OSU) and its contribution to educating architects and engineers. Due to the increased need to reduce energy costs associated with artificial lighting, coupled with health benefits from natural light, the use of the daylighting lab has now become much more relevant. The daylighting laboratory is used by both architecture and architectural engineering undergraduate students as part of the "integrative design studio", which is usually taught by 5 to 6 faculty members at the SOA including the second author. This typically includes students testing scaled physical models in the daylighting lab, to improve their initial design by admitting enough daylight and achieve uniform distribution of light as possible. To further understand the impact of the daylighting laboratory on faculty and student education, the authors conducted three separate surveys, consisting of multiple-choice questions and an open-ended question. Separate surveys were sent to current students, and alumni who have previously used the facility as part of the studio. In addition, another survey was sent to the 6 current faculty members involved in teaching the 'integrative design studio', and 2 retired faculty who have previously taught the studio but are currently not involved in teaching this course anymore. Results show that a majority of current and former students acknowledge that they have gained extensive knowledge on daylighting by testing their models in the laboratory, which turned out to be useful in practice. Both students and faculty strongly agreed that there is a need to allow other departments within OSU, such as Physics and Mechanical Engineering to utilize the laboratory for graduate research, since the current use of the facility is restricted to undergraduate education within the SOA. Based on the survey results, future work will include inter-departmental collaborations that will enable students from other departments within OSU to access the daylighting lab for research, besides incorporating collaborative work with design firms involved in daylighting design. Given the recent interest in daylighting and its association with occupant comfort and energy efficiency, it is expected that this facility will continue to assist in educating architects and engineers on this topic, enabling them to contribute to the industry and the building science community at large.

Keywords: Daylighting laboratory; Architects and Engineers; Survey; Education; Building Performance

1. Introduction

According to the United Nations, significant amount of energy consumption is by buildings, which includes about 74% of electric power (Energy Information Administration, 2023) – see Figure 1. Most of the energy consumption of buildings is due to artificial lighting and HVAC systems [1]. Due to increased energy costs coupled with the push for using renewable energy sources, such as solar energy, the subject of daylighting has gained tremendous importance in recent times. In addition, sunlight has been associated with health benefits including improved sleep and vitamin D production, although exposure to prolonged duration of sunshine may hurt the eyes due to excessive light intensities [2].

Therefore, it is necessary to allow the optimum amount of daylight that can prevent occupant discomfort while providing sufficient illumination levels to offset energy costs. Commonly used methods to design daylighting in buildings are based on approximate 'rules of thumb' which do not consider various factors affecting daylighting in buildings, such as sky condition, sun angles, location and size of window etc [3].

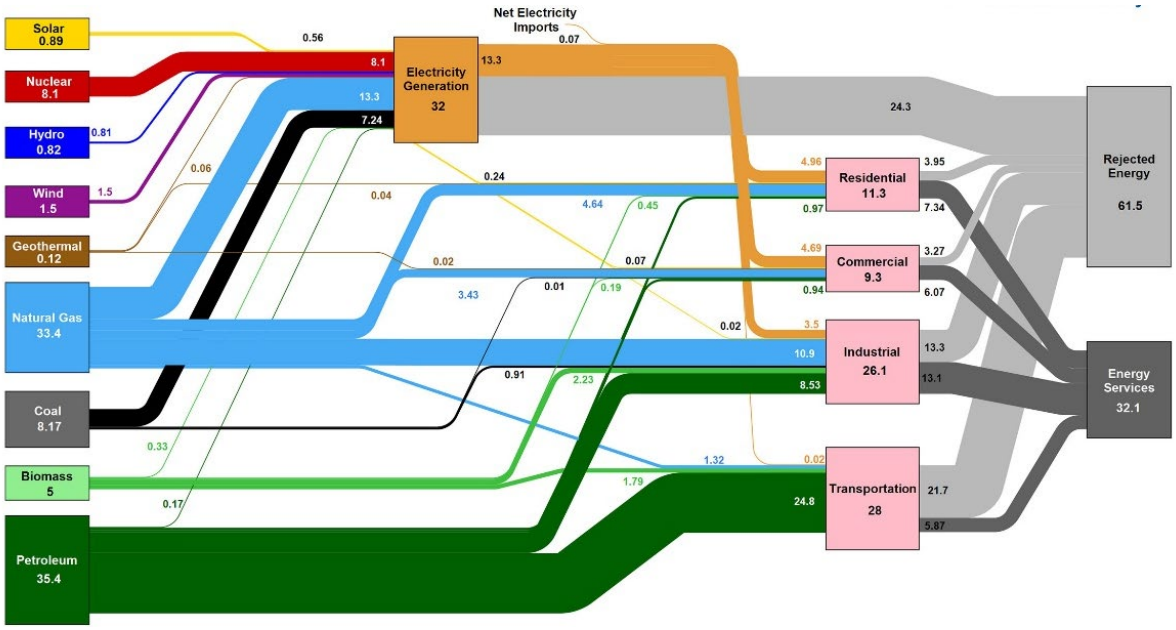


Figure 1. Estimated US Energy consumption in 2023 [source: Lawrence Livermore National Laboratory, downloaded from: https://flowcharts.llnl.gov/]

To overcome this lack of user-friendly design assisting tools, the second author of this article decided to develop the artificial sky dome laboratory (currently housed in the "daylighting laboratory") that can simulate different sky conditions, with no "star effect" to measure illuminance in the building model, in a controlled laboratory environment. A brief description of the facility is provided here while additional information about the laboratory and instrumentation can be found in [3] and [4]. The objective of this case study is to assess the impact of the daylighting facility on educating architects and engineers at the SOA and its contribution to the building science fraternity at large. For this reason, three separate surveys were conducted among faculty and students, past and present. Results show that most students greatly benefited from using the daylighting laboratory, particularly because of the hands-on experience. Faculty members believed the laboratory should be accessible to other departments, such as Physics or Mechanical Engineering, to carry out advanced scientific research.

2. Daylighting simulation methods

There are several analytical and experimental methods of simulating daylighting in buildings, a few of which are described in this section.

a) Rule of 2.5, which assumes that sufficient daylight within a workspace reaches a depth that is about 2.5 times the height of the window head above the work plane. Although this rule is typically applicable for clear glazing, window width being half the exterior perimeter length, and with no major obstruction [5, 6].

b) 15/30 rule, which assumes that within a 15 feet perimeter, sufficient daylight may be provided for office tasks, although partial daylighting may be achieved up to 30 feet depth [7].
c) $1/10^{th}$ rule, which assumes that the minimum daylight factor in a room is equal to one-tenth of the window area expressed as a percentage of the space's floor area [7].

Table 1. List of selected heliodon's and sky domes at various universities

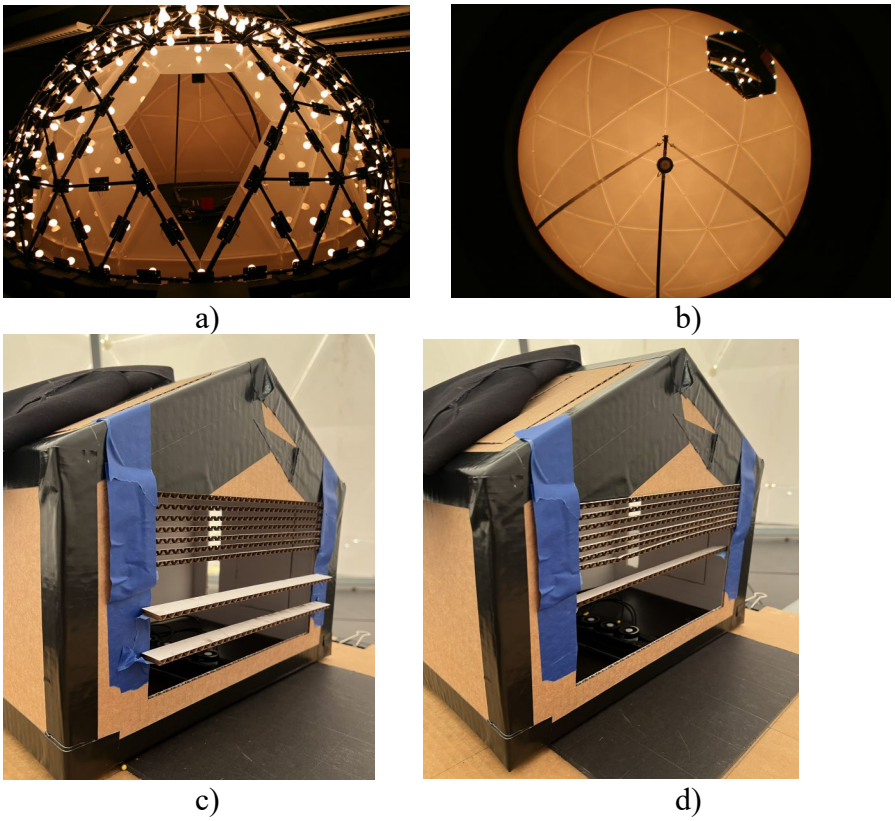
Daylighting simulator type	Location	Main features
Manual sun emulator heliodon	Auburn University, USA	• consists of 7 rings representing the sun paths for the 21st day of each month [8]. • Cradle supporting the rings can be rotated to simulate latitudes from equator to the poles, while the model being tested is fixed. • Used mainly for teaching and as a design tool for architects.
Manual sun emulator heliodon	Southeastern Louisiana University, USA	• Can simulate all latitudes from equator to polls. • Used primarily for teaching and demonstration purposes.
Manual sun simulator heliodon	Ball State University, USA	• facility is housed within the Center for Energy Research Energy Service (CERES) at Ball State University. • capable of providing imaging of shadow-casting beam light from the sun but cannot simulate sky vault illumination and overcast sky conditions. • Used for research and student demonstration.
Direct light simulator	EPFL, Lausanne, Switzerland	• Used to examine the interaction of sunlight and light distribution in a building, in a year. • Light source is fixed while the scaled building model can be moved. • Often used in conjunction with the scanning sky simulator [9].
Heliodon within the lighting research laboratory	University of Kansas, USA	• Located within a 750 square foot space in the "lighting research laboratory" • The heliodon is used for both graduate research as well as undergraduate studies. • Consists of multiple windows with adjustable ceilings for testing different types of lighting systems.
Artificial sky simulator	Cardiff University, UK	• Uses an 8m diameter artificial sky consisting of 640 lamps, which can replicate the various sky conditions. • The facility is used for graduate research and undergraduate student demonstrations [10].
Artificial sky simulator	University College London, UK	• Utilizes a 5.2 m hemispherical dome with more than 800 LED computer-controlled lights to simulate an artificial sky.
Artificial sky simulator	Stuttgart University of Applied Sciences (HFT), Stuttgart, Germany	• Consists of a 4.2m diameter translucent hemisphere with 360 fluorescent lamps that can be dimmed from 1 to 100% • A halogen bulb with parabolic reflector is used to simulate the sun with parallel sunlight. This facility can reproduce the sky's brightness and circumsolar radiation.

Computer based tools such as "Radiance" are also used to simulate daylighting in a room [11], but its use requires a strong understanding of daylighting design, not for beginners [3]. The rules of thumb described above provide students with a starting point in the design of daylighting systems, but do not provide a hands-on tool to assess daylighting. Experimentally, daylighting can be

simulated using a 'heliodon' or by an 'artificial sky dome'. A heliodon can simulate the movement of the sun but cannot model the effect of changing sky conditions (e.g. overcast skies). To accurately evaluate daylighting performance of a building, an artificial sky dome is used which can simulate standard sky conditions, besides direct sunlight, diffused sky and ground reflection [3]. A list of selected heliodon's and sky domes are presented in Table 1 with their features, although this is not a comprehensive list. The daylighting lab at the SOA is discussed briefly in the following section.

3. Daylighting laboratory at the School of Architecture, OSU

In 2004, the second author secured a grant from the National Science Foundation (NSF) to construct a daylighting laboratory to enhance research and education within the undergraduate program at the SOA. The daylighting laboratory consists of a dome (Figure 2a) with enough lamps that can be individually controlled to simulate the sun, different sky conditions, (Figure 2b), besides reflections from the ground and obstruction of nearby structures.



a) b) c) d)

Figure 2. Daylighting laboratory at the SOA: a) front view; b) overcast sky simulation; c) building model with exterior shading devices being tested; d) building model with interior shading devices being tested

All the instrumentation and equipment were installed in 2005, following which the laboratory was fully functional. The SOA currently offers undergraduate programs in architecture, architectural design studies and architectural engineering, of which only architecture and architectural engineering students enroll in the "integrative design studio". The "integrative design studio"

which includes the use of the daylighting laboratory as one of the requirements in the course, is typically taken by 5th year students of architecture and architectural engineering. This studio course is taught by 4 or 5 faculty members including the second author who is the director of the daylighting laboratory. The students determine the daylighting factor based on illumination levels measured inside and outside the model (Figure 2), which is then used to calculate energy savings using the technique described in [3]. For the last twenty years since its inception, the daylighting laboratory has been used by several undergraduate students at the SOA. Table 2 presents a summary of the features of the daylighting laboratory.

Table 2. Features of the daylighting laboratory at the SOA

Established in	2005 through an NSF grant obtained by the second author
Used as part of	Integrative design studio which is taken by undergraduate students of architecture and architectural engineering in the 5th year.
Features of the daylighting laboratory	• simulates various sky conditions including overcast skies, besides direct sunlight, diffused sky and ground reflections. • used to calculate the daylighting factor based on readings taken inside and outside the scaled building model. • The facility is primarily used for undergraduate education within the SOA.
Contribution of the daylighting laboratory to the architectural community	• Students have published in conferences and symposiums based on measurements performed at the laboratory [12] • Students graduating from the SOA have advanced knowledge about daylighting which is helpful in their professions.

To further understand the impact of this facility towards educating architects and engineers, besides making further improvements, the authors decided to conduct three separate surveys among students and faculty as described further.

4. Objectives and methodology

The present study seeks to:

- assess the impact of the daylighting laboratory in the context of undergraduate education to architects and engineers,
- make changes and improvements in future to the daylighting laboratory and means to enhance student education.

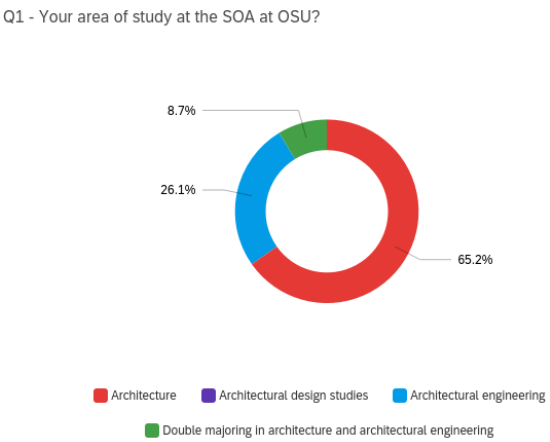
To achieve the above objectives, the authors decided to conduct three separate surveys among:

- current students at the SOA taking the integrative design studio,
- past students (alumni) who have used the daylighting laboratory as part of the integrative design studio and,
- faculty members (past and present) who are associated with teaching the studio.

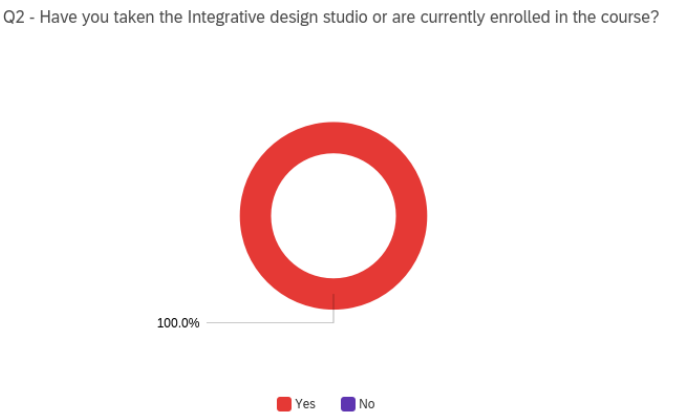
Each survey consisted of multiple-choice questions and one open-ended question which was distributed among the three groups. The survey was developed using “qualtrics” software and the questions were anonymous, without seeking any personal information from any of the respondents. The results are presented in the form of pie charts for each survey in Figures 2, 3 and 4 as discussed further. It must be noted that the second author was also part of the faculty survey but not the first author, since the latter is not involved in teaching the ‘integrative design studio’ course.

5. Results and Discussion

Survey results from the current students who are enrolled in the integrative design studio, and past students (alumni) who took the studio are presented in Figures 3 and 4, respectively. Survey results from the faculty are presented in Figure 5. The surveyed students currently in the program at the SOA, typically utilize the daylighting laboratory to test building models for measuring the daylight distribution in the building, as part of the integrative design studio course. The students generally work in groups of 3, with approximately 20 to 25 groups every year. Each group spends approximately 30 to 40 minutes to test their model, and re-test if needed to improve the daylight distribution by altering various parameters such as window/skylight size and location. In addition, students taking the advanced building performance course, *Sustainable Design in Architecture* to use the lab to evaluate several design iterations of daylighting systems and compare their performance to a code-compliant baseline. In this course, students spend about four weeks on the design and evaluation of daylighting systems.



a)



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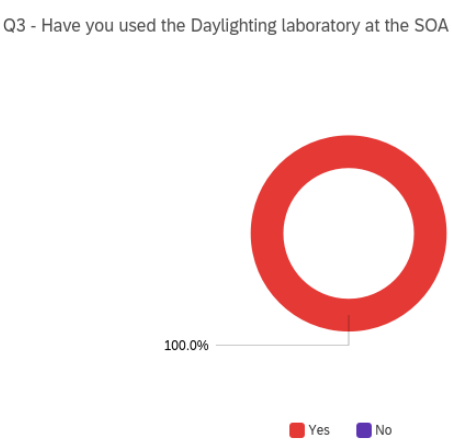

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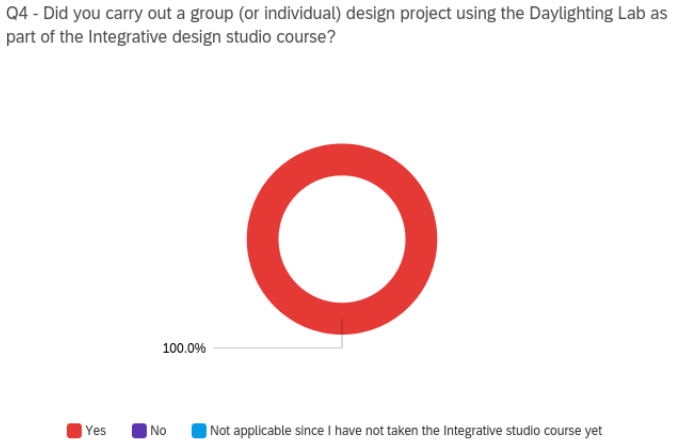
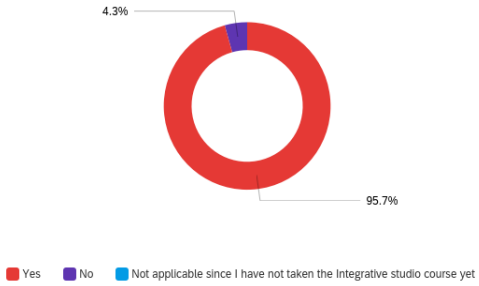


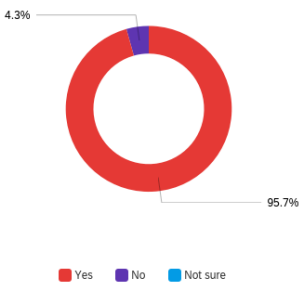
d)

Q5 - Do you feel that you have gained a better understanding by testing your physical model using the daylighting lab at the SOA?



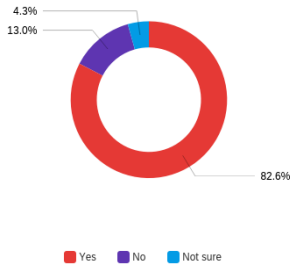
e)

Q6 - Do you think testing your model in the daylighting lab helped you make design decisions, such as adjusting area and shape of windows, skylights and glass selection?



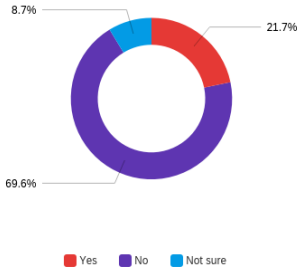
f)

Q7 - Do you think testing your model in the daylighting lab improved the overall design and performance of your proposed design?



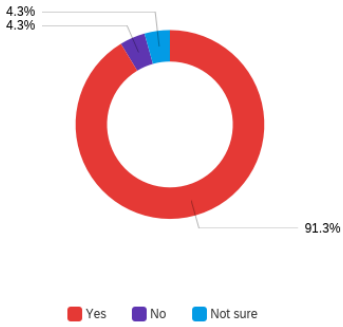
g)

Q8 - Have you faced any barriers or difficulties using the daylighting lab?



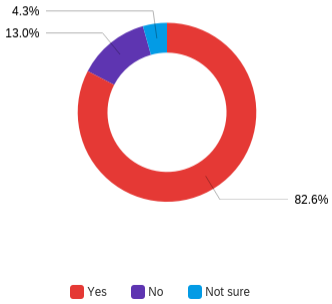
h)

Q9 - Would you recommend continuing to use the Daylighting lab as part of the Integrative design studio?

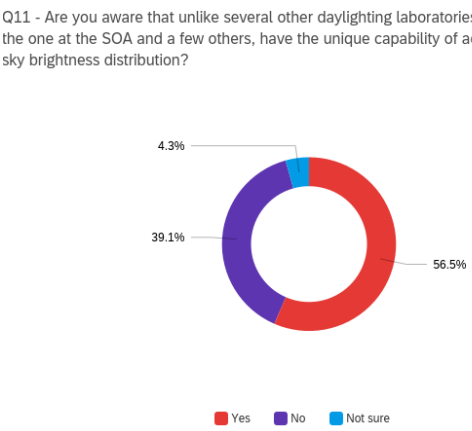


i)

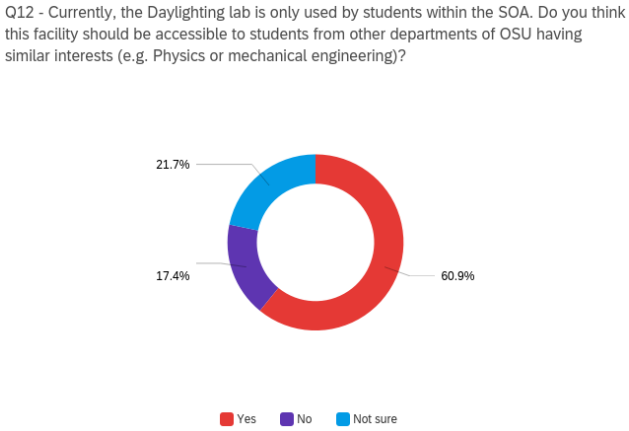
Q10 - Do you think the experience gained from using the Daylighting lab will be helpful in practice, given the importance of energy savings and occupant comfort associated with daylighting?



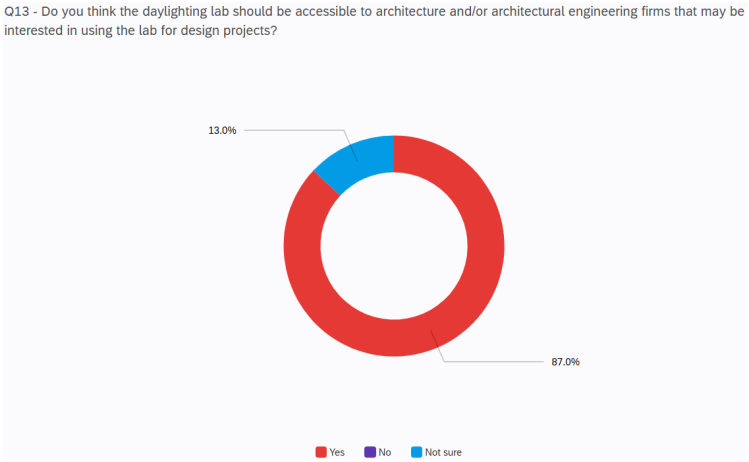
j)



k)

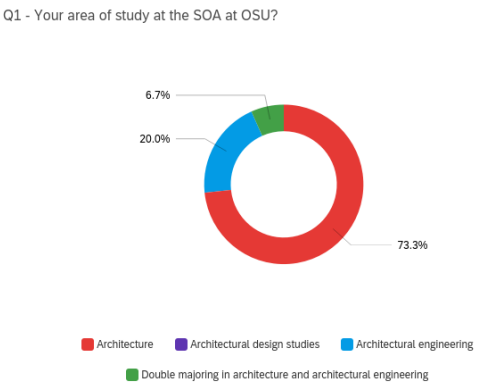


l)

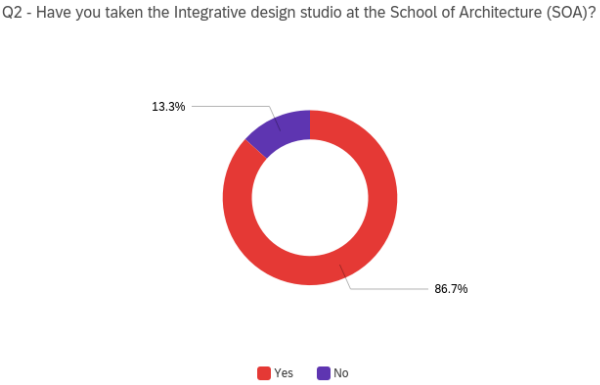


m)

Figure 3. Results from the survey conducted among current SOA students.

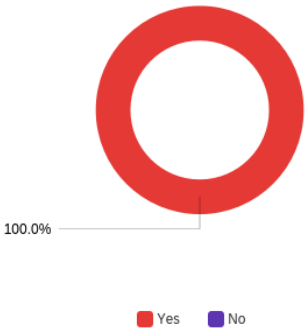


a)



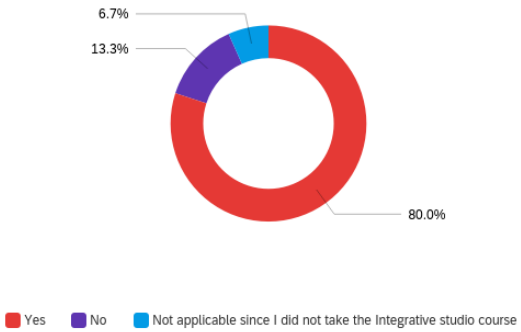
b)

Q3 - Have you used the Daylighting laboratory at the SOA?



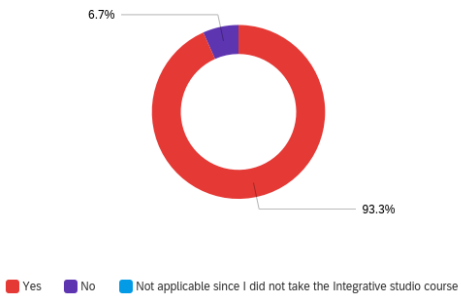
c)

Q4 - Did you carry out a group (or individual) design project using the Daylighting Lab as part of the Integrative design studio course?



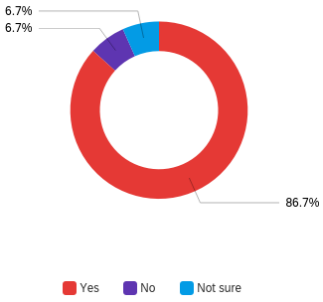
d)

Q5 - Do you feel that you have gained a better understanding by testing your physical model using the daylighting lab at the SOA?



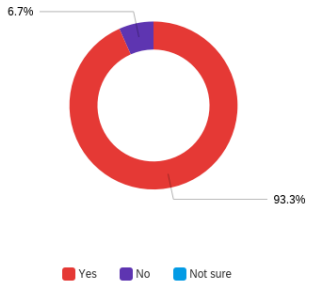
e)

Q6 - Do you think testing your model in the daylighting lab helped you make design decisions, such as adjusting area and shape of windows, skylights and glass selection?



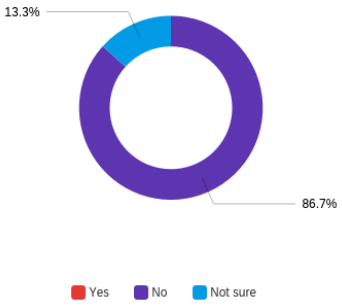
f)

Q7 - Do you think testing your model in the daylighting lab improved the overall design and performance of your proposed design?



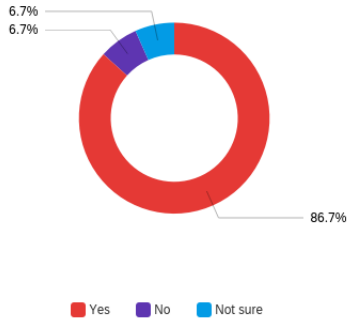
g)

Q8 - Did you face any barriers or difficulties using the daylighting lab?



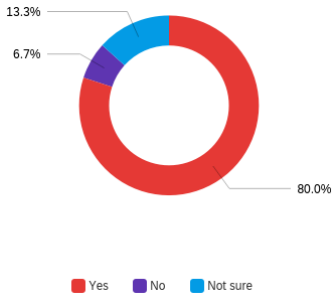
h)

Q9 - Would you recommend continuing to use the Daylighting lab as part of the Integrative design studio?



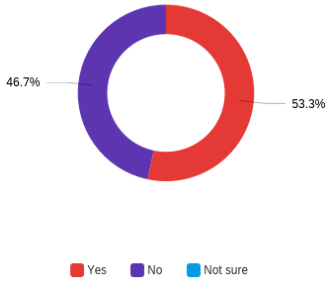
i)

Q10 - Do you think the experience gained from using the Daylighting lab will be helpful in practice, given the importance of energy savings and occupant comfort associated with daylighting?



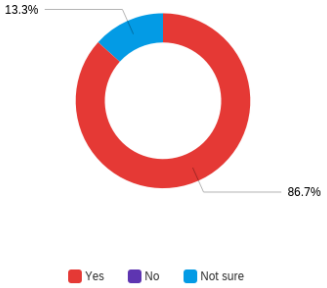
j)

Q11 - Are you aware that unlike several other daylighting laboratories across the world, the one at the SOA and a few others, have the unique capability of accurately simulating sky brightness distribution?



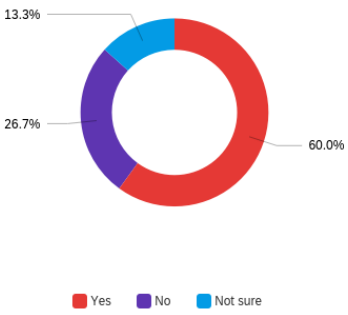
k)

Q12 - Currently, the Daylighting lab is only used by students within the SOA. Do you think this facility should be accessible to students from other departments of OSU having similar interests (e.g. Physics or mechanical engineering)?



l)

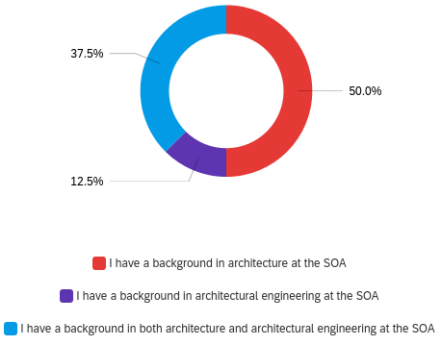
Q13 - Do you think the daylighting lab should be accessible to architecture and/or architectural engineering firms that may be interested in using the lab for design projects?



m)

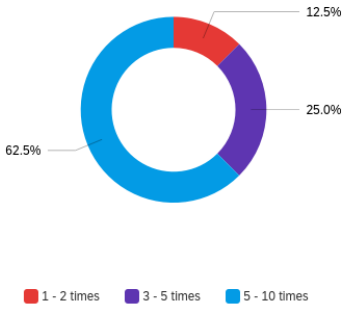
Figure 4. Results from the survey conducted among alumni of the SOA

Q1 - Which of these options best describe you?



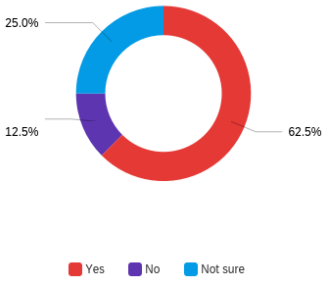
a)

Q2 - In the last 10 years, how many times have you been involved in teaching the Integrative Design Studio course at the SOA?



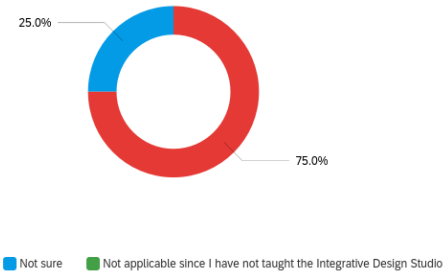
b)

Q3 - As a faculty member at the SOA, have you used the Daylighting laboratory so far or would you be interested in future?



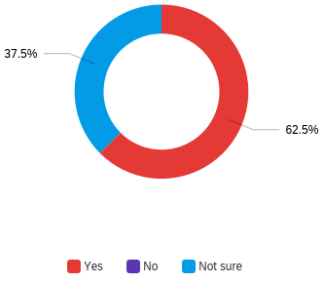
c)

Q4 - If you taught the Integrative Design Studio in the last 10 years, would you recommend to continue using the Daylighting lab as part of the Integrative design studio?



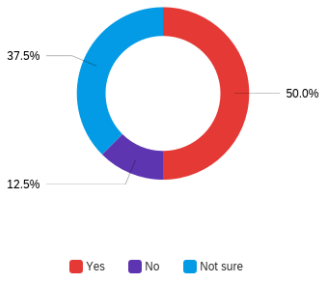
d)

Q5 - Currently, the Daylighting laboratory is only used by students within the SOA. Do you think this facility should be accessible to students from other departments of OSU having similar research interests (e.g. Physics or mechanical engineering)?

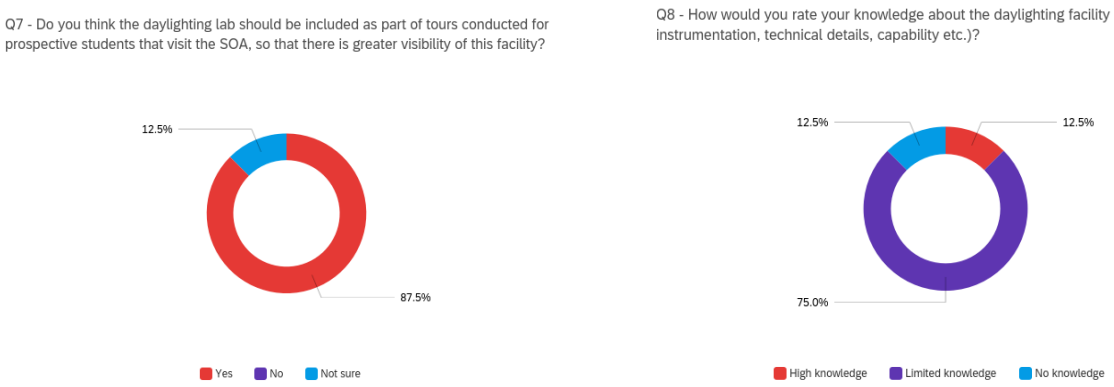


e)

Q6 - Currently, the Daylighting lab is only used by students within the SOA. Do you think this facility should be accessible to architecture and/or architectural engineering firms so that they can use it for design projects?



f)



g) h)

Figure 5. Results from the survey conducted among SOA faculty

5.1. Discussion of results from current students surveyed at the SOA

There were 23 students who responded to the survey. Results show that most current students at the SOA are majoring in architecture (65.2%), with a smaller number of students pursuing architectural engineering (Figure 3 (a)). At the time of the survey, all the students had used the daylighting lab as part of the integrative design studio course (Figure 3 (b,c,d)). Most students also felt that they had gained additional knowledge from using the daylighting lab, which helped them develop better designs for their projects (Figure 3 (e,f,g)). Due to the positive experience gained by current students, they recommended continued use of the lab for integrative design studio (Figure 3(h,i,j)). However, several students were unaware that the daylighting lab could simulate sky brightness (Figure 3 k), which implies that greater emphasis on educating the students about the facilities and capabilities of the daylighting lab is needed. In addition, most students were open to the idea of the lab being used for research by other departments, such as Physics and Mechanical Engineering at OSU, besides being accessible to design firms involved in daylighting projects (Figure 3 (l,m)). It is equally interesting to learn from recent graduates of the SOA about their experience of using the daylighting lab, as discussed in the following section.

5.2 Discussion of survey results from SOA alumni

From the 15 SOA alumni that responded to the survey, most of them had used the daylighting lab as part of the integrative design studio and had gained sufficient knowledge to design their projects for improved daylighting performance (Fig. 4 b to Fig. 4g). Most alumni felt the need to make the lab accessible to design firms and other departments at OSU (Figure 4 (l,m)), although several respondents were not aware of the lab's sky brightness simulation capabilities (Figure 4k). In general, the survey responses from current students and alumni show that there is an interest in the subject of daylighting since the students recognize the importance of daylighting in energy efficient building design. Furthermore, the students enjoy the idea of using the facility since it gives them a means of understanding daylighting principles applied to building design through hands-on work, which is encouraging.

5.3 Discussion of results from surveys conducted among current and past faculty at the SOA

Among the 8 respondents, 6 of them are current faculty members including the second author of this article that currently teaches the integrative design studio, which includes the use of the daylighting laboratory. Two of the respondents are retired faculty members that taught the design studio during their tenure as faculty at the SOA. About 50% of the faculty involved in teaching the

integrative design studio have a background in architecture, with about 37.5% of them having a background in architecture and architectural engineering (Fig.5a). The interaction between faculty and students with backgrounds in architecture and architectural engineering is extremely useful for teamwork and enhanced learning. A majority of faculty members have taught the studio course besides using the daylighting lab (Figure 5 (b,c)). Almost 62.5% of them felt the need to allow other departments within OSU to use the lab for research, besides 50% of them being in favor of making the lab accessible to design firms (Figure 5 (e,f)). Besides recommending the use of the lab for future studio course offerings (Figure 5 d), the faculty also felt the need to include the daylighting lab as part of tours for prospective students for greater visibility (Figure 5g).

5.4 Scope for future work and improvements

The current students, alumni and faculty were asked an open-ended question about making improvements for future. Several of those suggestions are currently under consideration for future, some of them include:

- Introducing the laboratory and its various applications, besides providing formal training on the use of instrumentation at the early stages of the design studio course.
- Having collaborative daylighting projects with design firms to gain a better understanding of the subject from a practical perspective.
- Making the lab accessible to research within OSU (e.g. interested faculty in Mechanical engineering or Physics).

Work is underway to have additional open-ended questions for future surveys, seeking suggestions from respondents for further improvements to the Daylighting Laboratory, and how this facility can be utilized to enhance education among architects and engineers.

6. Conclusions

This article presents an overview of the daylighting laboratory constructed in 2006 at the School of Architecture, Oklahoma State University and its contribution to educating architects and engineers. The daylighting laboratory is used by both architecture and architectural engineering undergraduate students as part of the “integrative design studio” course. To further understand the impact of the daylighting laboratory on student education, the authors conducted three separate surveys, consisting of multiple-choice questions and an open-ended question. Separate surveys were sent to current students, and alumni of SOA who have previously used the facility as part of the studio. In addition, another survey was sent to the 6 current faculty members involved in teaching the ‘integrative design studio’, and 2 retired faculty of OSU who have previously taught the studio but are currently not involved in teaching this course anymore. Results show that a majority of current and former students feel that they have gained extensive knowledge on daylighting by testing their models in the laboratory, which turned out to be useful in practice. Both students and faculty strongly agreed to the need to allow other departments within OSU to utilize the laboratory for graduate research, since the current use of the facility is restricted to undergraduate education within the SOA. Based on the survey results, future work is underway to enable students from other areas within OSU to access the daylighting lab for research, besides incorporating collaborative work with design firms involved in daylighting design. Given the recent interest in daylighting and its association with occupant comfort, it is expected that this facility will assist in educating architects and engineers on this topic, enabling them to contribute to sustainable building design.

Acknowledgements
The second author would like to thank the National Science Foundation (NSF) for their financial support which enabled the construction of the daylighting laboratory in 2005.

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