ACCESSIBLE LIGHTING DESIGN IN THE WORKPLACE: REDUCING THE NEGATIVE IMPACT OF PHOTOSENSITIVITY AND MIGRAINES

by

ALEJANDRO BECHTLE

A THESIS

Presented to the Department of Architecture
and the Robert D. Clark Honors College
in partial fulfillment of the requirements for the degree of
Bachelor of Architecture

June 2021

An Abstract of the Thesis of

Alejandro Bechtle for the degree of Bachelor of Architecture
in the Department of Architecture to be taken June 2021

Title: Accessible Lighting in the Workplace: Reducing the Negative Impact of Photosensitivity and Migraines

Approved: ______________________________________

Professor Alison Kwok, PhD

Lighting design in the workplace influences productivity, quality of life, and ability to come in to work the following day. For people with photosensitivity, especially those with migraines, poor lighting design is a serious concern. Migraine disorder affects 12% of the general population and women are three times as likely to suffer from migraines as men. Migraines can last for hours or days, cause significant pain, and reduced productivity is positively correlated with an attack's severity. This study investigates the relationship between migraine headaches and lighting design in the workplace. The study begins with existing research on migraines and considers other conditions, including epilepsy, autism, aging eyes, and depression. Lighting case studies of Lawrence Hall 405 and Gerlinger Hall 143 and 144 apply principles deduced from secondary research. Physical analysis includes illuminance values, daylight factor plans, and HDR images from data collected on September 22nd, 2020 and March 22nd-23rd, 2021. The spaces selected are disparate examples of workplaces that are occupied around the clock. A survey was conducted from April 1st-30th, 2021 to show users' opinions on the spaces investigated for this study. Both spaces could potentially induce migraines and have inconsistent lighting, which can dampen productivity.

Acknowledgements

I would like to thank Professors Alison Kwok, Michael Moffitt, Judith Raiskin, and Fred Tepfer for helping me fully examine accessible lighting design and consider the various perspectives and contexts involved in connecting photosensitivity to architecture. I am sincerely grateful for having the privilege of working with excellent mentors who are willing to guide me through this strenuous but rewarding process. Fred Tepfer, my second reader, helped me find my thesis topic and gave me incredibly helpful advice on how to connect my interests in studying accessible design to a physical case study. Professor Alison Kwok, my primary advisor, graciously took the time and effort to meet with me throughout my research and provided invaluable guidance. Professor Michael Moffitt, my CHC representative, and Professor Judith Raiskin have significantly aided my research process by contributing their ideas and suggesting paths for my investigation. I also want to thank Lilika Hanson, my life partner and fellow Clark Honors College student, for supporting my entire thesis process, encouraging my research, and assisting physical case studies by holding and transporting equipment.

Thank you to the creators of this template, CHC Librarian Miriam Rigby and CHC Academic and Thesis Coordinator Miriam Jordan. I would like to thank Reed for providing their Thesis Template for the inspiration of many elements of this template.

Table of Contents

List of Accompanying Materials in the Appendix

1. Collection of HDR images of Lawrence 405, Gerlinger 143 and Gerlinger 144

2. Survey distributed to students in the School of Architecture and Environment

3. All anonymous quotes from the distributed survey

List of Figures

Introduction

I have learned about the interplay between architecture and ocular migraines over the past decade. In middle school, I began missing school due to migraines. Going to the school cafeteria, with its bright lights and white floors, could trigger migraine attacks that could last the rest of the day or week. Even if I could manage the pain, ensuing vestibular disturbances limited my productivity. Thankfully, my school accommodated me and allowed me to eat lunch in a different room with more subtle ambient lighting. Still, I wished the common spaces were more hospitable environments for people who share my extreme sensitivity to bright light.

I chose to investigate accessible lighting design because I want to learn how to design for photosensitive individuals. Although I am focusing on workspaces, which includes classrooms, the basic premise stands for residential and civic design as well. During pandemics and for those who work from home, living quarters double as workspaces.

This investigation is largely based in secondary research because migraine disorder and lighting design have already been investigated separately. I am joining these ideas together and studying workspaces that are often occupied 24 hours per day. I chose Lawrence 405 and Gerlinger 143 and 144 due to their distinct lighting conditions and the mixed opinions of both workspaces. The irony of these physical case studies is that I developed a migraine while measuring the electric lighting in Lawrence 405. Because I was purposefully observing the space and analyzing it for potential migraine triggers, I was able to pinpoint what caused the attack. I developed an aura after measuring the illuminance values while facing a fluorescent luminaire that was in ill-repair and had a low-frequency flicker. The aura gave way to a migraine within an hour.

As a future architect, I will be responsible for the welfare of the people who will live, work, and learn in the buildings I design. I feel it is my duty to learn and understand how to design for everyone, including those who have photosensitivity like myself or reduced vision. The limitations of my thesis cannot contain this goal; this is the beginning of a long journey toward understanding universal design.

To implement design strategies, a designer must first justify its necessity. So, this investigation begins with a thorough explanation of photosensitivity, migraines, and existing problems in lighting design. This research is meant to expand readers' knowledge of migraine disorder and the effects of lighting design on photosensitive users. Contrary to my own beliefs before beginning this investigation, designing for photosensitivity is far more than controlling the intensity of light. Flicker frequency, glare, and even chromatic aspects of light all affect the quality of life and experience people have within the built environment.

Background

Photosensitivity

Definition

Photosensitivity, also known as photophobia, is an aversion to light due to pain and/or discomfort. In this definition, “light” generally refers to bright light, but flickering and glare can also cause an adverse reaction. Treating photosensitivity is complex and some temporary treatments worsen the condition. Those who use dark glasses, for example, risk dark adaptation, which increases their sensitivity.[1]

The definition of photosensitivity applied in this thesis includes a spectrum from severe pain caused by bright light to those with “hemeralopia” or “day blindness,” which can be a painless condition.[2] Photosensitivity is closely related to the eye and the orbit, but it is frequently caused by differences in the brain.[3]

Causes

There are several neurological, physical, and psychological conditions associated with photosensitivity. Many of these conditions have a high comorbidity rate, so it can be unclear which condition is causing light aversion. Because photosensitivity can also manifest in a variety of ways between individuals with the same root cause, the relationship between these conditions and photosensitivity has too many variables for simple conclusions.

---

[1] Digre and Brennan, “Shedding Light on Photophobia,” *Journal of Neuro-ophthalmology,* (March 2013): 11.
[2] Ibid, 1.
[3] Ibid, 4-5.

Many neuro-ophthalmic disorders cause photosensitivity.[4] Migraines are the most common clinical condition associated with photosensitivity.[5] Migraineurs are usually more sensitive to light than the general population, even between attacks.[6] Headaches besides migraines, such as tension headaches, also cause photosensitivity.[7] People with migraines are also more likely than the average person to have epilepsy and vice versa.[8] There are some theories stating these conditions could be functionally related. Those with epilepsy are also more likely to be on the autism spectrum, which is also associated with photosensitivity.[9] Other neurological conditions, like blepharospasm, a condition causing involuntary blinking, can also increase light sensitivity.[10]

Physical conditions that cause photosensitivity are often temporary and result from an infection or injury. Inflammation in the iris, ciliary body, eyelids, or retina can decrease ocular tolerance for light.[11] Non-inflammatory eye conditions such as pigmentosa, a breakdown of the retina, and cone dystrophies can cause light aversion and/or day blindness.[12] Brain conditions such as pituitary tumors, apoplexy (subarachnoid hemorrhage), meningitis, and traumatic brain injuries can also cause

---

[4] Digre and Brennan, ibid, 1.
[5] Ibid, 9.
[6] "Shedding Light," 3.
[7] Ibid, 3.
[8] Trenité et al., "Headache, Epilepsy, and Photosensitivity: How are they Connected?," *The Journal of Headache and Pain,* (October 2010): 470.
[9] Selassie et. al., "Epilepsy Beyond Seizure: A Population-Based Study of Comorbidities," *Epilepsy Research*, (December 2013): 309-10.
[10] Digre and Brennan, "Shedding Light," 3.
[11] Ibid, 2.
[12] Ibid.

photophobia, despite having little to no physical relationship with the eyes.[13] Even lifelong conditions like progressive supranuclear palsy can cause photosensitivity.[14]

Several psychological conditions are frequently comorbid with photosensitivity. For example, bright light can agitate people with agoraphobia.[15] Those patients may feel more comfortable going outside while wearing dark glasses. New studies show that people with depression, anxiety, and/or panic disorder are more likely to have decreased light tolerance thresholds. The associated light aversion can be improved with therapy and behavior interventions, but it is not considered purely "psychiatric," meaning it is not "all in their head."[16] Depression and anxiety are often comorbid with migraines, so it can also be unclear which condition is causing light sensitivity.[17]

Prevalence and Association with Migraines

Migraines and photosensitivity have a strong relationship, regardless of how the migraines or light aversion manifest. Light is not the only migraine trigger and light sensitivity does not always result in pain. However, due to the increased photosensitivity in people with migraines between and during attacks, lighting affects migraineurs more than the general population. This means bright light can have a negative impact on their quality of life, even if it does not explicitly cause pain.

---

[13] Digre and Brennan, "Shedding Light," 2-4.
[14] Ibid, 4.
[15] Ibid, 4.
[16] Ibid.
[17] Ibid.

Defining Migraines

Migraines are more than a bad headache; they are a neurological condition that usually results in headaches and causes "auras" in 25% of migraineurs.[18] By definition, migraine disorder without an aura is a disorder causing recurrent headaches with moderate to severe pulsating pain lasting 4-72 hours.[19] Associated symptoms include nausea, vomiting, dizziness, numbness and/or tingling in the face or extremities, and extreme sensitivity to light, sound, and/or smell.[20] Migraines are usually on one side of the head and focus around one eye socket, but one third of attacks affect both sides.[21] An individual must have five attacks to be diagnosed. Migraines with an aura are similar, but include temporary neurological disturbances, typically lasting no more than one hour. Auras can occur without a proceeding headache. An aura may include visual disturbances, tingling, numbness, vertigo, tinnitus, ataxia, slurred speech, and/or decreased levels of consciousness.[22] To be diagnosed, aura symptoms must not be attributable to any other condition and must occur on at least two separate occasions.

Migraine disorder is a result of hyperresponsivity to both environmental and internal stimuli.[23] It is not clear how migraines occur, but there is a strong theory that explains the relationship between auras and the headaches that usually follow. Cortical spreading depression, a wave of altered brain activity, followed by prolonged neurological inhibition causes auras.[24] Inflammation proceeds this event and causes

[18] "Migraine Facts," migraineresearchfoundation.org, Accessed March 14, 2021.
[19] Peggy Berry, "Migraine Disorder: workplace implications and solutions," *Aaohn Journal,* (2007): 51.
[20] Migraine Research Foundation, "Migraine Facts"
[21] Ibid.
[22] Berry, "Migraine Disorder," 51.
[23] Demircan et al., "The Impact of Migraine on Posterior Ocular Structures," *Journal of Neuro-ophthalmology,* (January 2015): 3.
[24] Demircan et al., "The Impact of Migraine," 3.

pain. Unfortunately, this process does not explain most migraines, which do not have auras.

There are subtle physical differences in brain and eye structure between migraineurs and the general population. People with migraines may have thinner retinal fiber layers in the nasal and nasal-inferior sectors, the areas of the retina that face the nose.[25] Their choroid, a layer of blood vessels in the retina, may also be thinner than average at the fovea, where the eye connects to the optic nerve.[26] Lastly, people with migraines seem to have pupils that are 0.27 mm larger than average.[27] These differences do not apply to all migraineurs, but they are statistically significant.

Migraineurs' eyes also have functional differences, which could be related to structural differences in the eyes and/or brain. Migraines can be considered a "visual pathway dysfunction" that happens between the retina and occipital lobe.[28] This may be caused by specific defects in the neurological pathways that process visual information.[29] Migraine disorder may affect migraineurs all the time, not just during attacks. According to a study conducted by Ö. Yenice et al, people with migraines have visual field deficits like reduced contrast sensitivity.[30] Within two days of an attack, migraineurs also have less responsive pupils with slow dilation.[31] This functional

[25] Ibid.
[26] Ibid.
[27] Mylius, Braune, and Schepelmann, "Dysfunction of the Pupillyar Light Reflex Following Migraine Headache," *Clinical Autonomic Research,* (February 2003): 17.
[28] Digre and Brennan, "Shedding Light," 3.
[29] Ibid, 10.
[30] Yenice et al., "Assessment of Spatial-Contrast Function and Short-Wavelength Sensitivity Deficits in Patients with Migraine," *Eye,* (February 2006): 219.
[31] Mylius et al., "Dysfunction,"17.

difference could indicate a strong physical aversion to light exposure, even after an attack has been resolved.

Migraine Triggers

Migraine attacks tend to significantly increase photosensitivity, but they are not always triggered by light. Only 50-75% of migraineurs can identify their triggers while keeping headache diaries.[32] Common triggers include: bright lights, flicker, glare, stress, caffeine, nutrition, changes in the weather, smoke, high altitude, certain odors, menstruation, pregnancy, and sleep patterns.[33,34] After a migraine is triggered, disruptive stimuli like bright or flickering light can prolong and/or worsen an attack.

Many factors that trigger or contribute to migraines are out of any individual's control, meaning pain management is the only option for many migraineurs. The medical community needs more information on migraines to help patients, but the research is underfunded. In 2017, only 0.50$ per migraineur was dedicated to migraine research by the NIH.[35] Because there is no universal treatment or cure for migraines, modifying migraineurs' physical environment to mitigate the negative impact of their condition is a worthwhile approach.

Migraines Defined as a Disability

Migraines are relatively common, but this does not preclude them from being a disability. The definition of "disability" accepted by the Center for Disease Control and

---

32 Friedman and De Ver Dye, "Migraine and the Environment," *Headache: The Journal of the Head and Face Pain,* (2009): 941.
33 Berry, "Migraine Disorder," 54.
34 Friedman and De Ver Dye, "Migraine," 941.
35 Migraine Research Foundation, "Migraine Facts"

World health organization has three requirements. To be considered a disability, a condition must impair a person's mental and/or physical functioning, limit their activities, and restrict their participation in normal daily activities.[36] Migraines fit this definition, as they inhibit learning and occupational functions. The World Health Organization rated migraine disorder as the 19th most disabling condition in 2007.[37] Now, according to the Migraine Research Foundation, the condition is considered the 6th most disabling illness.[38] The higher rating of disability could be a result of new research or the consideration of a broader range of symptoms caused by migraines.

Acknowledging the prevalence of migraines and their impact is helpful when justifying an architectural response. Architecture must already accommodate physical disabilities, so asking architects to consider other forms of disability is not excessively expanding their responsibilities. However, any added considerations require additional funding. So, arguments for changes in workplace design must be supported by evidence for the necessity of this accommodation.

---

36 CDC, "Disability and Health Overview," Accessed March 15, 2021.
37 Berry, "Migraine Disorder," 51.
38 Migraine Research Foundation, "Migraine Facts"

The Impact of Migraines

Quality of Life

Migraines can coexist with depression and worsen an individual's mental health.[39] Chronic migraines are especially likely to increase the risk of depression, anxiety, and sleep disturbances.[40] Four million U.S. citizens have chronic migraines, which means they have at least 15 migraine days per month.[41] Migraine disorder usually does not escalate to this point, but overuse of pain medication is the most common reason migraine disorder becomes this severe.[42]

Humans are social animals and the inability to participate in normal daily functions or socialize with friends and family will generally have a negative effect on mental health. So, it is no wonder that migraineurs are more likely to have mental health concerns. In the United States alone, people with migraines spend three million or more days in bed each month.[43] In a study conducted by *Aaohn Journal* in 2004, 40% of respondents with migraines avoided household chores for 5 or more days due to migraines and 10% had skipped housework for 15 days.[44] Sadly, 70% of respondents had skipped social events, leisure activities, or family gatherings due to migraines.[45]

The prevalence and impact of migraines may be partially due to undertreatment. Only 43-45% of self-reported migraineurs seek medical care for this condition, the rest

---

39 Berry, "Migraine Disorder," 52.
40 Migraine Research Foundation, "Migraine Facts"
41 Ibid.
42 Ibid.
43 Lerner et al., "The Migraine Work and Productivity Loss Questionnaire: Concepts and Design," *Quality of Life Research*, (December 1999): 700.
44 Weiss, Bernards, and Price, "Working through a migraine: addressing the hidden costs of workplace headaches," *Aaohn Journal*, (2008): 496.
45 Ibid.

opt for self-treatment, which may be more affordable.[46] Of those who do seek treatment, only 4% consult headache and pain specialists.[47]

Migraine disorder often surfaces in childhood; half of migraineurs have their first attack before their twelfth birthday.[48] There is evidence that babies as young as eighteen months can have migraines.[49] Children with migraines are twice as likely to stay home from school as those without migraines.[50] This necessary absenteeism continues into adulthood and contributes to presenteeism, meaning reduced productivity due to illness. This happens when migraineurs run out of sick days.

Economic Cost

The individual economic cost of migraines affects the entire household. Medical expenses can be 70% higher in families with migraineurs than those without.[51] The increased healthcare cost accounts for migraines and comorbid conditions. According to data analysis conducted in 2015, migraineurs spent $5.4 billion on treating chronic migraines and at least $35.6 billion more on the rest of their conditions.[52]

Indirect costs, like decreased income, compound the price of treating migraine symptoms. According to a study conducted in the United States in 2001, migraines are associated with a 20.3% decrease in women's income and a 10.2% decrease in men's income.[53] These statistics do vary and African American migraineurs seem to have a

46 Berry, "Migraine Disorder," 51.
47 Migraine Research Foundation, "Migraine Facts"
48 Ibid.
49 Ibid.
50 Ibid.
51 Ibid.
52 Ibid.
53 Berry, "Migraine Disorder," 52.

5.9-9.1% increase in income, but migraines correlate with reduced earnings for most U.S. citizens.[54] In European studies, there is no clear correlation between migraines and reduced income, possibly due to different sick day policies.[55]

Companies are indirectly affected by their employee's migraines. In 2008, it was estimated that migraines cost employers $12 billion per year.[56] This figure is likely to increase with inflation. Part of the economic loss is due to sick days; U.S. employers lose 157 million workdays each year due to migraines.[57] Presenteeism may be a larger economic factor, but it is less measurable. The pain and discomfort migraine disorder causes can be too frequent to stay home for but intense enough to limit normal functioning. This means the migraineur suffers by being unable to treat their pain at home and the employer loses productivity, especially if the migraine persists due to lack of treatment.

Demographic Disparities

Migraines affect everyone, but the condition affects women and people of working age significantly more than other demographics. According to the Migraine Research Foundation, 6% of men, 18% of women, 10% of children, and 12% of the overall population have migraines.[58] Women are more likely to suffer from chronic migraines, possibly because fluctuating estrogen levels increase the chance and severity of attacks.[59] Half of all female migraineurs have one migraine per month, 25% have

---

[54] Berry, "Migraine Disorder," 52.
[55] Ibid, 52-3.
[56] Weiss, Bernards and Price, "Working Through a Migraine," 495.
[57] Migraine Research Foundation, "Migraine Facts"
[58] Migraine Research Foundation, "Migraine Facts"
[59] Ibid.

four or more migraines per month, and 85% of people with chronic migraines are women.[60] The definition of "working years" varies, but it is common consensus that people in their working years are significantly more likely to have migraines. In the 25-55 year old range, 7.2-9.7% of men and 21.5-27.3% of women have migraines.[61] In addition to social prejudices, lighting design could be among the invisible barriers many women face in the office.

Because working age people have a significant chance of suffering from migraines, it stands to reason that offices should be designed to accommodate them. Unfortunately, offices often have fluorescent lights in rows along the ceiling and they may be over lit. Bright light usually improves visibility and productivity. But excessive lighting can have the opposite effect on migraineurs because it can trigger or worsen a migraine, which reduces productivity and causes increased absences.

Effects of Lighting on Photosensitivity and Migraines

Migraines are incurable and not always preventable. However, the built environment, especially lighting design, can increase or decrease the negative impact migraines have. What factors in the built environment contribute to or worsen migraines? How can architects help improve the quality of life and productivity of migraineurs through their designs?

To create equitable lighting schemes that consider the needs of all users, particularly those with photosensitivity and migraines, designers must consider lighting holistically. Carefully analyzing multiple lighting factors before building construction

---

[60] Ibid.

[61] Berry, "Migraine Disorder," 52.

will help people with migraines, those with other photosensitive conditions, and the general population.

Illumination Intensity

Bright light is a hindrance to those with photosensitivity. According to a study conducted in 1997, just 500 lux -1,000 lux can cause migraineurs pain and headaches.[62] Of the migraineurs who participated in this study, 74% said they were photosensitive at all times and 100% said they had photosensitivity during attacks.[63] There are separate studies showing that the general population's light discomfort threshold is either 1,000 lux or 2,500 lux.[64] Lighting over these thresholds can cause discomfort or pain for anyone, but it may be debilitating for a migraineur. For the idealized lighting design model proposed in this investigation, these illumination levels are impermissible.

Flicker and Chromatic Spectrum of Light

Flicker can be either a blatant or insidious migraine trigger. The strobing effect of certain luminaires causes discomfort in everyone, even when it is imperceptible. During saccades, imperceivable moments of blindness while our eyes move, flicker distracts our visual processing, which can induce headaches.[65] Migraineurs are often more sensitive to flicker, but migraine attacks are not the only problem flicker may trigger.[66] Flicker between 4 and 60 Hz is dangerous because it can cause seizures in

---

62 Vanagaite et al, "Light-Induced Discomfort and Pain in Migraine," *Cephalagia,* (April 1997): 736.
63 Ibid, abstract.
64 Winterbottom and Wilkins, "Lighting and Discomfort in the Classroom," *Journal of Environmental Psychology*, (2009): 64.
65 Wilkins, "A Psychological Basis for Visual Discomfort: Application in Design," *Department of Psychology, University of Essex,* (September 2015): 49-50.
66 Karanovic et al., "Detection and Discrimination of Flicker Contrast in Migraine," *Cephalagia,* (Aprill 2011): 730.

some people with photosensitive epilepsy.[67] Some fluorescent bulbs can create this frequency, particularly when they are turning on or are past their prime performance period.[68] A room lit with poorly maintained fluorescents that are triggered by motion sensors is a classic example of lighting with unacceptable levels of flicker.

Controlling for flicker is not solely increasing frequency to reduce negative effects. If it is not possible to stay well above 300 Hz, it may not be worthwhile to upgrade lights. Due to patterns created on the retina by certain frequencies, 300 Hz can be worse than 100 Hz, though both are problematic.[69] Risks of adverse reactions to flickering lights increase with long exposure, high luminance, and large illuminated area.[70]

Ideally, all luminaires would have a flicker speed well above 300 Hz, but this may indicate increased expenses. Lack of funding can result in poorly maintained, inexpensive luminaires, which results in low flicker frequencies. In a study conducted in 2009, 80% of investigated classrooms had luminaires with a 100 Hz flicker, a frequency known to cause headaches.[71] The prevalence of cheap fluorescent bulbs in classrooms could be contributing to increased absences seen in children with migraines.

Glare and Contrast

Sharp contrast between two illuminated surfaces can give anyone a headache, but migraineurs seem especially uncomfortable with high contrast lighting.[72] Even high

---

[67] Wilkins, "Visual Discomfort," 51.
[68] Ibid.
[69] Ibid.
[70] Ibid.
[71] Wilkins, "Visual Discomfort," 51.
[72] Ibid, 45.

color contrast can induce discomfort or headaches.[73] Glare is more noticeable with electric lighting, so designers should be careful with luminaire placement.[74] According to Arnold J. Wilkins, human eyes are most comfortable with images that have a 1/f amplitude spectrum and many luminaire arrangements differ significantly from this ideal contrast ratio.[75] Figure 1 on the following page shows two negative examples of lighting arrangement, but the arrangement on the left is far worse. Bands of bright lights can create significant discomfort due to contrast. If we consider the fluorescent bulbs in this photo, this store may induce discomfort from glare *and* flicker.

Figure 1: Lighting Arrangement Comparison

(Wilkens et al 2015): 50.

Summary

I am proposing three principles of lighting design that would create a comfortable environment for photosensitive users. These principles may benefit all users, but they are especially important for migraineurs.

---

73 Ibid, 49.
74 J. Duijnhoven, “"Systematic review on the interaction between office light conditions and occupational health: Elucidating gaps and methodological issues," *Indoor and Built Environment* (2019): 166.
75 Wilkins, “Visual Discomfort,” 50.

1. Ambient illumination should be 1,000 lux or less, below 500 lux if possible. Providing even dimmer areas in offices may benefit photosensitive individuals, potentially allowing them to work more effectively and with less pain.

2. No luminaire should include bulbs with a flicker speed of 300 Hz or below. This may be out of a designer's control, but it should be strongly recommended to clients. Providing data on the problems caused by flicker may encourage compliance with this guideline.

3. Image contrast should not diverge from a 1/f amplitude spectrum if possible. At minimum, this means avoiding bright bands of luminaires surrounded by dimmer surfaces. This creates significant glare and may induce discomfort or migraines, especially in combination with flicker or high luminance.

It is necessary to set a lower bound for illumination. Although dimmer lighting may be better for some, it is an exclusive detriment for others. Light is important for normal daily activities and morale.

Opposing Lighting Needs

Universal design is more than accommodating a single condition or symptom. To create equitable lighting conditions, a designer needs to consider a broad range of needs, including those that oppose one another. If there were only photosensitive people, lighting design would already cater to them. Brightly lit rooms are popular because they can have positive health benefits and help those who have decreased visual capacity.

Reduced Vision

After people reach 40 years old, our eyes need an ever-increasing amount of light to see. Older eyes need at least 300 lux of ambient light, 1,000 lux of task lighting, and reduced glare.[76] Depending on the condition of an individual's eyes, their lighting needs may be higher than 300 lux or even 1,000 lux. Brighter light can be more comfortable for people who have a visual impairment because it helps with wayfinding and orientation. This means that individuals with severely impaired vision who do not have photosensitivity would greatly prefer an "excessively lit" space that could cause pain for a photosensitive migraineur.

Benefits of Bright Light

Bright light during the day can have wonderful health benefits and improve individual mental states. There is evidence that rooms with at least 1,000 lux increase physical and mental well-being, though this effect is dampened after one hour if the lighting is electric.[77] Short periods of increased illuminance can have day long positive effects. For example, increasing illuminance from 750 lux to 2,500 lux for two hours in the morning then one hour after lunch boosts alertness, improves moods, and helps regulate sleep-wake cycles.[78] Keep in mind that 2,500 lux is the upper bound of the general population's lighting comfort threshold and this condition could have detrimental effects on migraineurs.

Brightly lit rooms are frequently rated as more pleasant and comfortable. Some may report better mental health while spending time in a brightly lit room.[79] Excessive lighting is unnecessary for improved mental health, but the threshold is above the levels

---

[76] Mariana Figueiro, *Lighting the Way: A Key to Independence*, (AARP Andrus Foundation: 2002), 4.
[77] Duijnhoven, ""Systematic review," 157.
[78] Ann Webb, "Considerations for Lighting in the Built Environment: Non-Visual Effects of Light," *Energy and Buildings,* (April 2006): 723.
[79] Duijnhoven, ""Systematic review," 158.

that suit people with high photosensitivity. Illuminance as low as 600 lux has similar ratings as 1,000 lux, but 300 lux is too dim to provide the benefits of a "bright" space.[80]

Benefits of a bright room are maximized with daylight and risks of high illuminance are maximized with electric lighting, especially fluorescents. So, the rules mentioned in the previous section still suit the need for bright lighting, but they can be amended. Luminance between 1,000 lux and 2,5000 lux may be acceptable if the added lighting is exclusively daylight and there are dimmer areas.

Architectural Applications

Applying holistic lighting design principles is crucial to human-centric design. Lighting affects comfort, visibility, safety, orientation, alertness, concentration, cognitive performance, sleep-wake cycles, mood, energy, stress levels, and even impulse control.[81] Controlling and utilizing daylighting is especially important. Ordinary tasks require a daylight factor of 1.5-2.5% and prolonged reading needs a 2.5-4% daylight factor.[82] This can be achieved with careful window placement, correctly positioned shading devices, and light shelves.

Daylighting has especially strong influences on human behavior and circadian rhythms.[83] Blue light, which is like mid-day daylight, seems to have the strongest positive impact on mood.[84] Light wavelengths between 446 and 488 nm activate human

---

80 Ibid, 165.

81 International Association of Lighting Designers, "JOINT POSITION PAPER ON HUMAN CENTRIC LIGHTING," *LIGHTING EUROPE: The Voice of the Lighting Industry*, (February 2017): 1.

82 Walter T. Grondzik and Alison G. Kwok, *Mechanical and Electrical Equipment for Buildings*, (Hoboken, NJ: John Wiley & Sons, Inc., 2015): 265.

83 Webb, "Considerations for Lighting," 725.

84 Ibid, 726.

and animal brains the most, including melatonin suppression processes.[85] Fluorescent bulbs and certain LED bulbs frequently emit this type of light.

Electric lighting is far easier to control. Lighting schemes with lower ambient lighting and task lighting with a high color temperature (62000 K) have been shown to increase productivity by 5% compared to standard ambient lighting.[86] Task lighting also reduces energy consumption and allows users to personalize lighting at their workstation. Conducting detailed lighting analysis throughout the design process can help prevent harsh glare or excessive lighting.

---

85 Ibid, 722.

86 Ishii et al., "Intellectual productivity under task ambient lighting," *Lighting Research & Technology*, (2018): 237.

Thesis Statement and Case Study Hypothesis

Statement

Accommodating photosensitivity and migraines in the built environment requires low to moderate ambient lighting, consistent daylighting, no glare, and carefully selected luminaires. Light does not trigger all migraines, and different aspects of light can trigger an attack depending on the individual. The primary goal is to mitigate the negative impact of this condition to improve users' quality of life and productivity.

Hypothesis

If the illuminance data reflects poor or strong lighting conditions, the survey results should reflect these findings. The qualitative data will pair with the quantitative data to support conclusions about Lawrence 405 and Gerlinger 143 and 144.

Lawrence 405 is well lit, but this space could strain users' eyes due to inconsistent lighting. Existing overhead electric lighting is sufficient for most users but could exceed the comfort threshold of migraineurs. Flickering lights may also produce dim spots and cause discomfort. Overall, Lawrence 405 is likely to have acceptable areas of lighting surrounded by workstations with different lighting concerns.

Gerlinger Hall 143 and 144 may be underlit, but the lighting is even. This means an electric lighting intervention, like task lighting on each desk, could uniformly improve these workspaces. Gerlinger Hall is likely below advisable illuminance values, but it has a more straight-forward path towards an idealized lighting condition.

Methods

Lawrence 405 and Gerlinger Hall 143 and 144 combined are a similar size and they both hold intermediate architectural studios courses. Their lighting conditions are disparate enough to show two separate examples of workspace evaluation according to the principles proposed in this thesis. Each space holds two separate studios, but neither has a solid division between the workspaces. These classrooms have the same lighting strategy: bands of fluorescent lights along the ceiling. But the Gerlinger Hall studios have minimal illuminance from electric lighting and modest daylighting, while 4th floor Lawrence Hall studios have ample daylight and substantial electric lighting. The ceilings in Gerlinger Hall are also lower, and the floor is black rubber instead of the polished concrete seen in Lawrence Hall; this emphasizes the dimness.

On September 22nd, 2020, between 12:30 pm and 1:45 pm, I captured 16 HDR of the target locations. I chose to collect them on the autumnal equinox to record an average lighting condition. I later converted these photos into false color images with PhotoSphere. The sky was overcast while I took the photos, which is common during the school year in Eugene, Oregon. The collection of HDR images includes images in each space, facing all four cardinal directions, with the mutable electric lighting turned off and on. The hallway lights in Lawrence Hall and the corridor lights in Gerlinger Hall remained on at all times because they cannot be turned off due to safety regulations. When evaluating these spaces, I considered all 16 images and their false color renderings. However, only four of these images are included in the results and analysis, because they adequately demonstrate the points I make in this investigation. Copies of all 16 HDR images and the 16 false color renderings are in the appendix.

On the same day, September 22nd, I recorded illuminance values with a combination of evenly spaced paces and a hand-held ruler. Due to the reduced accuracy of this method, I recorded the daylight illuminance values again on March 23rd, 2021, three days after the spring equinox, and the first sunny day of Spring 2021. For the second data set, I measured each point, placed them on a 5' grid and marked them with tape. I used a light meter from Alison Kwok's lab to measure the lux values at the same level as the studio workplane. I recorded the electric lighting illuminance values on the same, marked points on March 22nd, 2021, the night before I measured the daylight. The new plans were not only more accurately spaced, but created a full set of electric lighting, daylighting, and combined lighting illuminance values. They are similar to the findings from September 22nd, 2020 and lead to the same conclusions, so they are the only plans that appear in this section. The previous plans are in the appendix.

To analyze the collected illuminance data, I recorded each data point next to a dot that corresponds to the tape marks in the classrooms. To get a daylight factor, I divided each value by the illuminance value from indirect light outdoors. To make the plans more legible, I color coded them based on lux and daylight factor values.

To complement the physical analysis, I conducted a survey that asked for feedback on lighting conditions in Gerlinger and Lawrence Hall studios. The Department of Architecture distributed this survey to the School of Architecture and Environment on my behalf. Due to the COVID-19 pandemic, few people have recently worked in these spaces, and newer students have not experienced in-person studio courses. However, the majority of respondents had worked in the fourth floor Lawrence Hall studios and/or the Gerlinger Hall studios. Because this investigation focuses on the effects of lighting design on people with photosensitivity, especially migraineurs, the recruitment message asked for participants with these conditions. As a result, a disproportionately high number of respondents have photosensitivity and/or migraines. The survey analysis focuses on individuals' experiences with Lawrence and Gerlinger Hall studios, noting that many respondents may have worked in different workspaces in the same general group of classrooms. My goal was to collect qualitative feedback on the lighting in Lawrence and Gerlinger Hall studios.

I conducted the survey after receiving approval from the University of Oregon's IRB. Because the Qualtrics survey was set up to be completely anonymous, this study qualified for an IRB exemption. In order to submit the survey, all respondents demonstrated explicit consent to participate and the results are not personally identifiable information. Raw results are not included in this document, because they are only meant to be presented in aggregate form, with the exception of voluntarily submitted anonymous quotes. There is a stored, confidential record of these results that has only been viewed by the primary researcher and the faculty advisor of this thesis. A copy of the survey is in the appendix.

Case Study Data and Analysis

Illuminance Value and Daylight Factor Plans

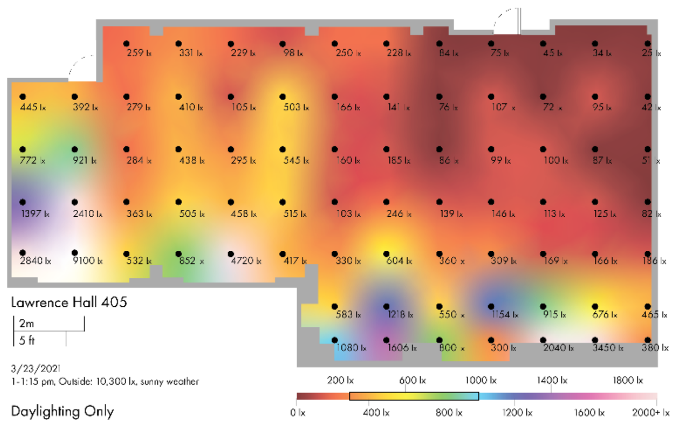


Figure 2: Daylighting in Lawrence 405

Lighting at the work plane between 1 pm and 1:15 pm on Tuesday, March 23rd, 2021.

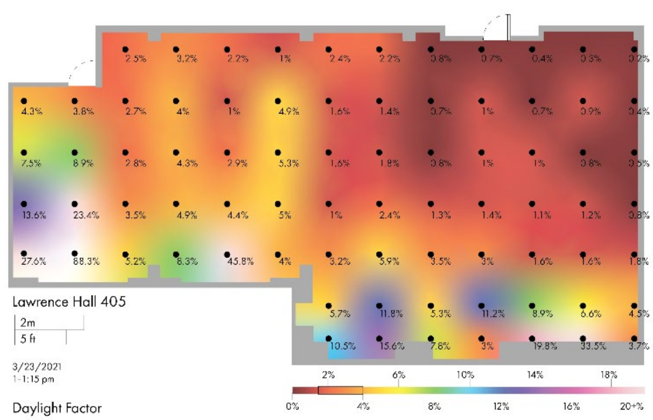


Figure 3: Daylight Factor in Lawrence 405

Daylighting values converted into daylight factor percentages using 10,300 lux, the average indirect outdoor daylight between 12:55 pm and 1 pm on March 23rd, 2021.

Lawrence Hall 405 has varied daylighting and few data points exceeded the 2,500 lux mark during documentation, most of the space had less than 1,000 lux of illuminance. Just under half the space was below the ideal working threshold of 300 lux, but most of Lawrence 405 had a daylight factor between 1.5% and 4%, which is ideal. If class had been held on March 23rd, 2021, the professor would have likely turned on the lights to compensate for dim areas.

With the lights off, Lawrence 405 should cause little to no discomfort for photosensitive individuals if they choose their workstation carefully. However, the light is too low for drawing or reading, so most users would turn on the lights. The fluorescent luminaires are also motion-activated, so anyone entering the room would be exposed to the electric lighting, even if they would rather work with pure daylight.

I collected this set of illuminance data-points on a sunny day, but the windows provide an overwhelming amount of daylight on most days due to high daylight factors. The primary concern with the daylight in Lawrence 405 is inconsistency, which can create undesirable contrast and make dimmer areas seem even darker.

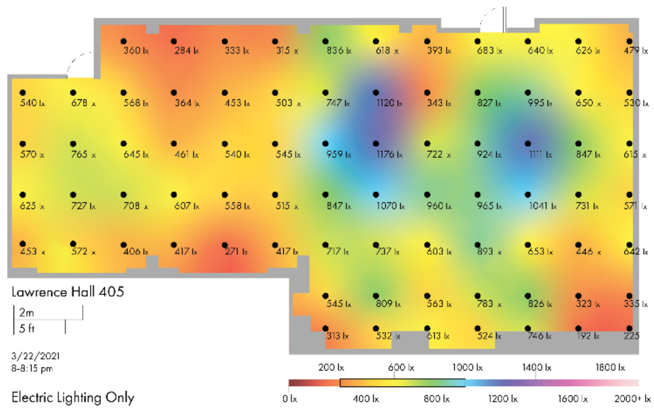


Figure 4: Electric Lighting in Lawrence 405

Electric lighting at the work plane was recorded thirty minutes after sunset on Monday, March 22nd, 2021. Electric lighting is composed of fluorescent luminaires in parallel rows, which are vertical lines according to the orientation of this plan. The upper left corner of this floor plan, in a low luminance area, includes a flickering luminaire with a frequency similar to a strobe light.

The electric lighting is more easily controlled than daylight, so it should not have major inconsistencies. The only exception would be subdivided spaces with different illuminance levels. Because this space is open, low to mid-range ambient lighting with available task lighting would be ideal. The electric lighting in Lawrence 405 varies significantly, due to declining operation in some luminaires. The sections that appear orange in this plan, which fall between 200 lux and 400 lux, are near visibly flickering fluorescent bulbs. In the upper left, there is a particularly dim bulb that has an unusually low flicker frequency. The areas that appear blue and purple, which have 900 lux to 1200 lux of illuminance, are near fully operational luminaires. If all light bulbs in Lawrence 405 were replaced, the illuminance values would likely be higher, except for specific corners that are shaded by columns or other obstructions.

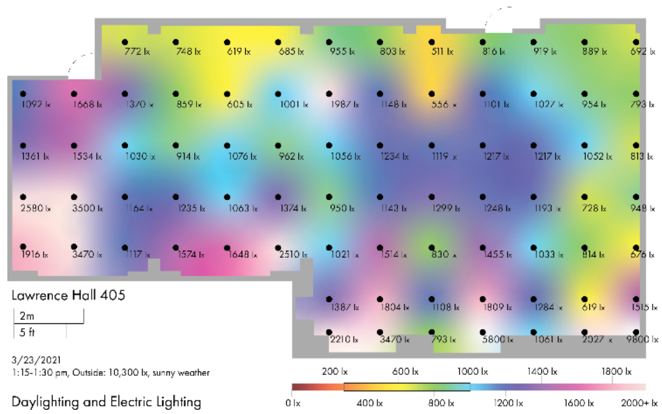


Figure 5: Daylighting Combined with Electric Lighting in Lawrence 405

A view of daylighting and electric lighting combined. The lighting levels will shift with solar azimuth, overhead clouds, and time of day. This is an example of full lighting at the beginning of vertical studios during Spring term.

Both the electric lighting and daylighting in Lawrence 405 are inconsistent and have excessively dim areas. Because lighting values are always in flux to some degree, both the electric and daylighting shifted somewhat between the illuminance values recorded for this graphic and the previous data sets. This is still a reasonable example for a sunny spring day during studio class hours. There are no values below 300 lux, but several data points exceed 2500 lux, which could hinder productivity. While the illuminance values for Figure 5 were being recorded, 64.9% of the marked data points exceed 1000 lux, which is a high discomfort threshold for migraineurs. This means studio class time could be uncomfortable and may trigger a migraine, especially when high illuminance values are combined with flicker and glare.

According to quotes from respondents, the lighting in Lawrence Hall can be distracting, uncomfortable, and create undesirable work environments. Respondents made comments such as “depending on where your studio desk is located, you might get a space that is too bright/dim," "the electric overhead lighting has had a big impact-especially the color or hue of the light which are often fluorescents in Lawrence hall," and "the motion sensor lights in Lawrence hall have been distracting and cause eye strain during long studio hours." One respondent offered an especially astute and detailed assessment of Lawrence Hall: "Depending on the specific Lawrence studio space and its windows' solar aspect, the effect of glare in some situations was exacerbated by dim lighting conditions. This heightened contrast, particularly on overcast days, had a distinct effect in degrading workspace visibility."

Most of the illuminance values in Lawrence 405 are in a good range for working but this space may be too bright for photosensitive individuals. Many areas are too dim or too bright in all lighting conditions. And the flickering/glare from the overhead luminaires could still trigger migraines or cause general discomfort.

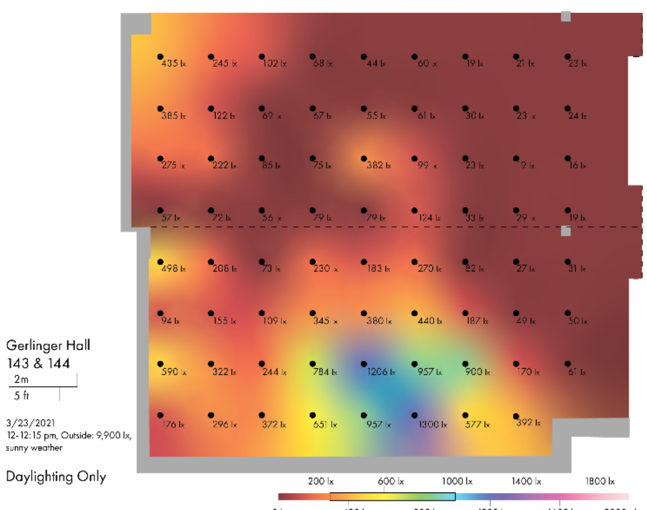


Figure 6: Daylighting in Gerlinger 143 and 144

Daylight measured at the work plane on Tuesday, March 23rd, 2021, between 12 pm and 12:15 pm.

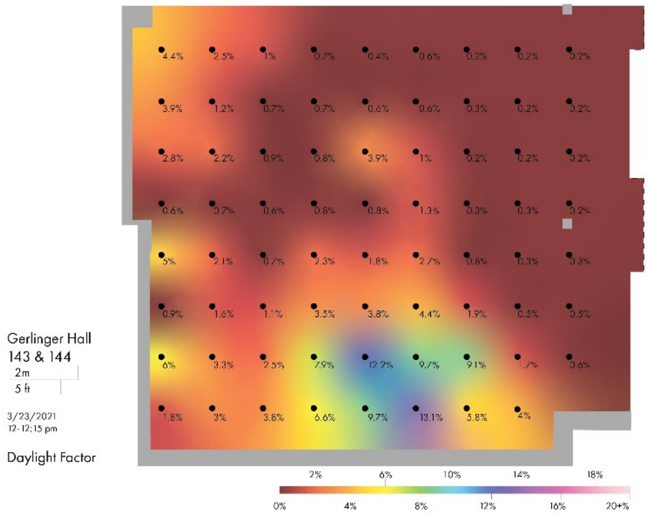


Figure 7: Daylight Factor in Gerlinger 143 and 144

Daylight lux values converted into daylight factor percentages using 9,900 lux, the average indirect outdoor daylight between 11:55 am and 12 pm on March 23rd, 2021.

Gerlinger Hall 143 and 144 have more consistent lighting than Lawrence 405, but the daylight does not penetrate the space and there are still excessively daylit areas. The exact location of these areas could depend on cloud patterns, the time of year, and the time of day. Despite being measured on a sunny day, 74.2% of the data points show in Figure 6 are below 300 lux. Electric lighting is necessary for productive work in these studio spaces.

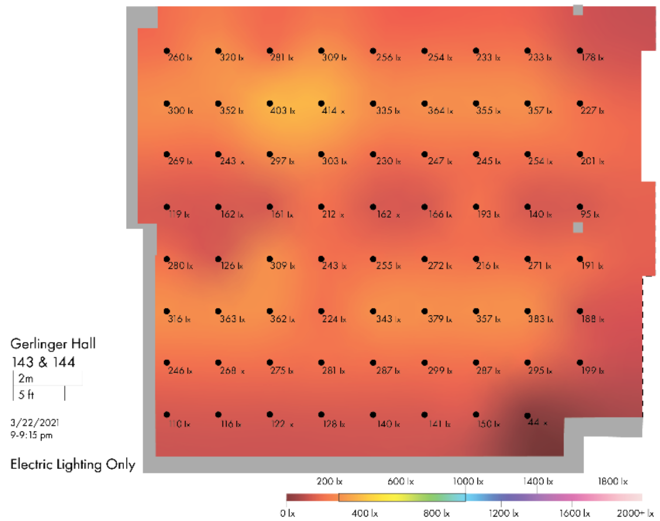


Figure 8: Electric Lighting in Gerlinger 143 and 144

Electric lighting measured at the work plane 90 minutes after sunset on March 22nd, 2021. The electric lighting is rows of fluorescent lights, similar to Lawrence Hall, but at a much smaller scale. The bands of lighting are horizontal according to the orientation of this plan.

Gerlinger 143 and 144 have fairly consistent electric lighting, but it is minimally sufficient. The same number of data points are below 300 lux with both the electric lighting only and daylight only conditions. The difference is that the electric lighting generally stays above 100 lux, and most values are over 200 lux. The luminaires in Gerlinger 143 and 144 had little to no visible flicker. The electric lighting is limited by sparse luminaires. Unlike the electric lighting plan for Lawrence 405, there is a clear striation in Figure 8 in the same direction as the arrangement of the luminaires. The shorter ceilings, narrower luminaires, and wide distance between light sources all contribute to the light pattern projected onto the work plane.

The electric lighting in Gerlinger 143 and 144 has no obvious migraine triggers, but it may strain students' eyes due to the low luminance values. This can reduce productivity and cause headaches.

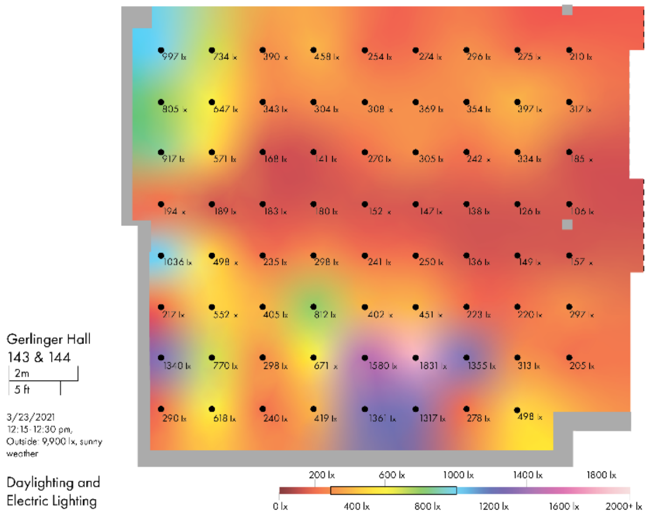


Figure 9: Daylighting Combined with Electric Lighting in Gerlinger 143 and 144

An example of daylighting and electric lighting combined 30-45 minutes before vertical studios during Spring term. Lighting measurements were taken at the work plane between 12:15 pm and 12:30 pm on March 23rd, 2021.

If students were working in Gerlinger 143 and 144 outside studio right before class time, they would work in the type of lighting condition shown in Figure 9. There are no data points that exceed 2500 lux, only 9.9% of data points exceed 1000 lux, and most of the room has over 300 lux. There is still a dim band along the dividing column line between Gerlinger 143 and 144, but no desks are placed there. This is a workable lighting condition, even though some areas may still be too dim. Unless a photosensitive person worked in one of the bright areas near a window, the luminance values in Figure 9 would be unlikely to cause significant discomfort. Glare and imperceptible flicker are the only potential migraine triggers in this lighting design.

Few anonymous quotes referenced Gerlinger Hall, most either referenced Lawrence Hall or studios in general. The quotes directed towards Gerlinger Hall disagree with one another. One participant said "Gerlinger provides more lighting options - which is very helpful," while another said, "Gerlinger Hall has no pleasant light and the space feels dark and dimm [sic], especially the floor, in its appearance and associated material qualities."

HDR Images

Figure 10: Lawrence 405 Facing North with only Daylight

An HDR image created on September 22nd, 2020, at 12:44 pm and its false color rendering.

As seen in Figures 2-4, Lawrence 405 has more lighting inconsistencies than Gerlinger 143 and 144. The dim areas shown in the illuminance plans of Lawrence 405 are visible in Figure 10, which shows a daylight-only condition. Most users would prefer working with the lights on, unless they are bothered by the electric lighting.

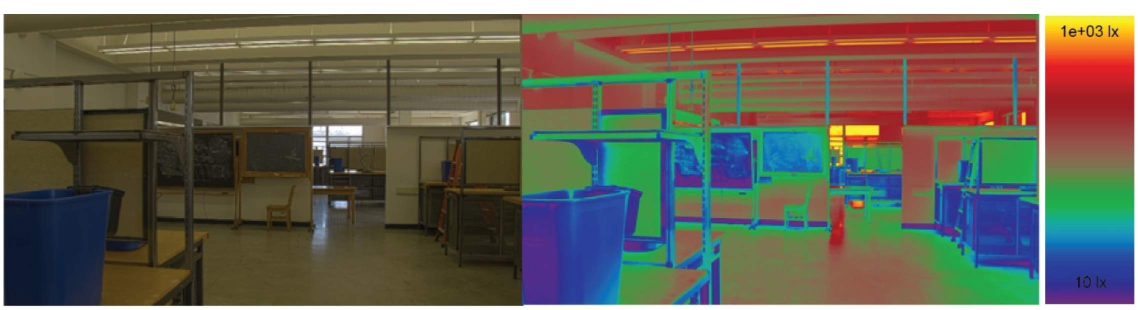


Figure 11: Lawrence 405 Facing North with Electric Light and Daylight

An HDR image created at 12:46 pm on September 22nd, 2020, showing the difference in contrast with the provided electric lighting.

The fluorescent bulb luminaires are motion-activated, so they would turn on when a student enters the classroom unless they were switched to "off," rather than "auto." With the lights on, Lawrence 405 has more visible glare and significant flicker.

Figure 12: Gerlinger 143 and 144 Facing East with only Daylight

An HDR image at a comparable angle to the figures shown for Lawrence Hall studios, demonstrating the contrast between the windows and surrounding room. This image was created at 1:45 pm on September 22nd, 2020.

Gerlinger 143 and 144 are excessively dim without electric light. The false color rendering demonstrates this more clearly than the original HDR image. There is perceptible glare from the windows because the rest of these basement studios have so little daylight. Users need to turn on the electric lights in these studios to work unless they prefer drafting and modeling with limited visibility.

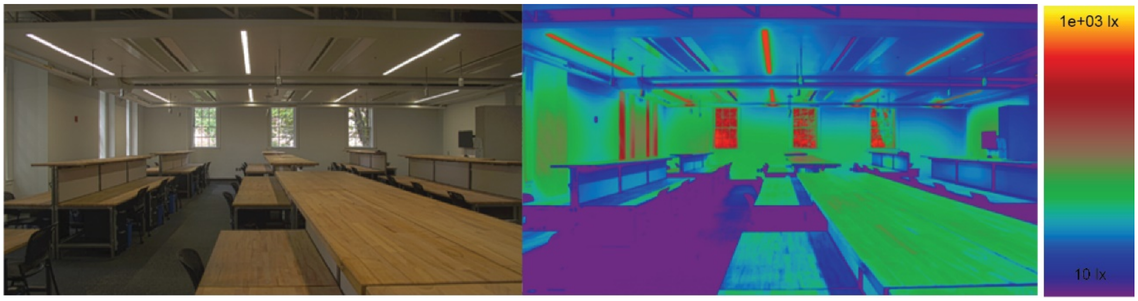


Figure 13: Gerlinger 143 and 144 Facing East with Electric Light and Daylight

An HDR image created at 1:43 pm on September 22nd, 2020, showing the dramatic increase in illumination with electric lighting in Gerlinger Hall.

Electric lighting significantly improves Gerlinger 143 and 144, but these studios are still fairly dim. The bands of luminaires are half the width of the luminaires in Lawrence 405 and the spacing between them is much larger. The dropped ceiling also creates some glare, because the light cannot diffuse above the fluorescent bulbs. The bands of vents between the luminaires seem, at first glance, to be more light sources that are simply turned off. But they do not produce light. If they did, these studios would likely foster greater productivity.

Survey Results and Analysis

The survey was conducted online via Qualtrics and had a total of 40 respondents, 75% of which were medically assigned female. This could affect results because estrogen levels affect the prevalence and severity of migraines. 37.5% of male-assigned participants reported having migraines, compared to 62.5% of female-assigned participants. 18.8% of female-assigned participants reported no photosensitivity or migraines, along with 50% of male-assigned participants. Age did not have a clear correlation with migraines; 62.5% of respondents were 18-25, 56% of which have migraines, compared to 57.5% of all respondents. Although 100% of respondents over 40 had migraines, this group was too small to lead to conclusions. The differences between male-assigned and female-assigned participants is significant, but it has reduced importance because few male-assigned people participated in this survey.

Participation was entirely voluntary, the survey was distributed to the entire School of Architecture and Environment, and no one was excluded from the survey. One response was empty, so it was discarded. All participants are in the field of Architecture, Interior Architecture, or Landscape Architecture. When asked if they had worked in 4th floor Lawrence Hall studios and/or Gerlinger Hall studios, 65% reported working in one or both of these spaces. Because some respondents rated spaces they may not have worked in, it is possible that there was at least one unintentional answer. If those responses are counted as individuals who've worked in these spaces, 67.5% of participants have worked in one or both spaces. This inconsistency in responses is noted in the figures they affect. Based on question number 8 alone, 35% of respondents haven't worked in either space, 17.5% have worked in both, 42.5% have only worked in the Lawrence Hall studios, and the remaining 5% have worked in Gerlinger Hall studios and not 4th floor Lawrence Hall studios.

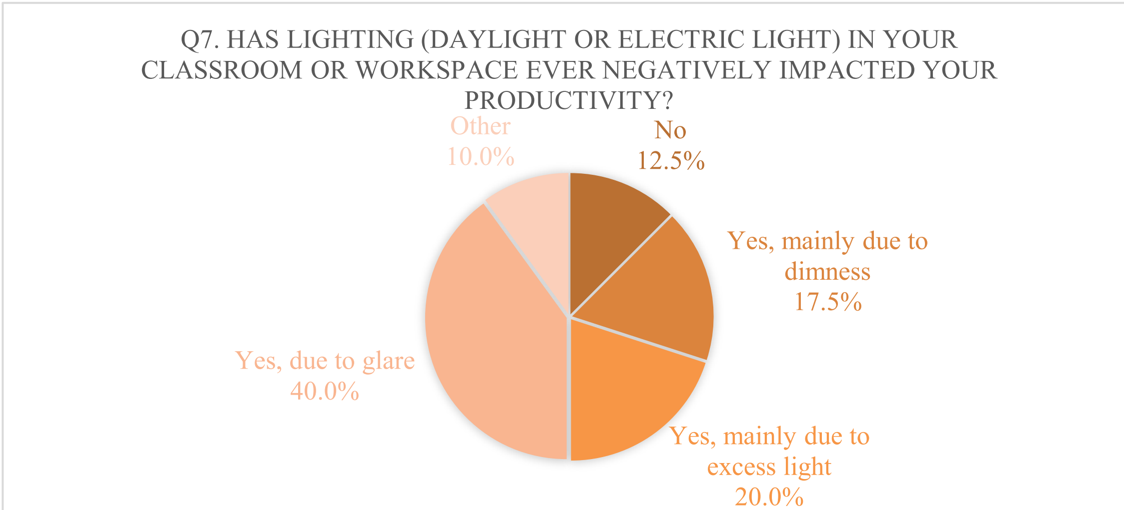


Figure 14: Reported Negative Reactions to Lighting in Workspaces

The most common problem with workspace lighting design reported by survey participants is glare, followed by excessive light and dimness. Question 7 was general, following questions were specific to Gerlinger and Lawrence Hall studios, so every participant responded to this question. “Other” includes issues like flicker.

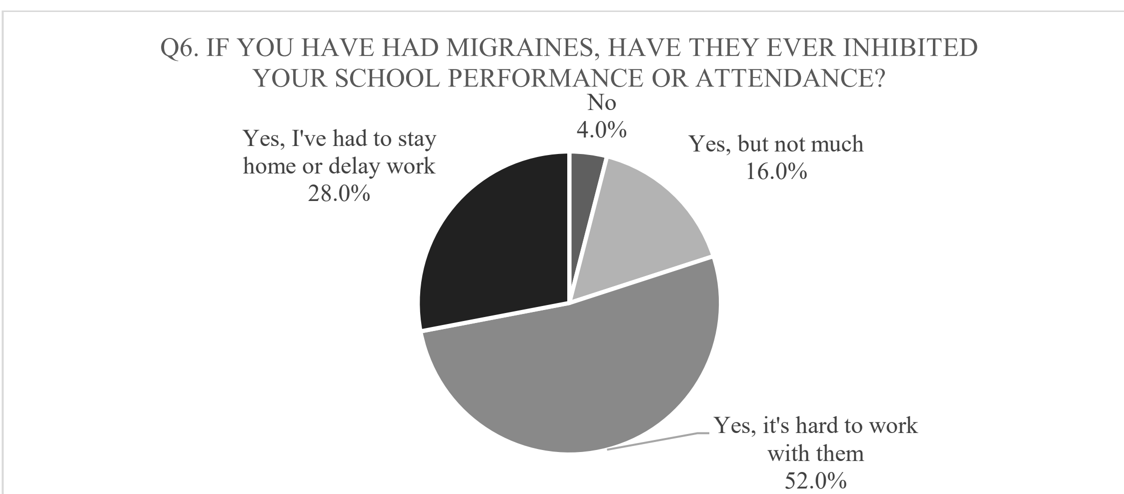


Figure 15: Survey Responses to the Impact of Migraines on Productivity

Distribution of migraineurs' responses to question 6. Note that some respondents who were not sure if they have migraines, but are sure they have photosensitivity, responded to this question. This accounts for 8% of replies describing the impact of migraines. Those who did not respond to question 6 or responded with "I don't have migraines" were excluded from this chart.

Of the respondents who chose to describe the impact of their migraines in question 6, 28% reported having to stay home or delay work to treat migraines. This was 17.5% of all survey respondents. The majority of migraineurs who participated in this survey work through them. Some migraineurs may reserve staying home for the worst attacks, so it is possible all participants with migraines work through them. This is related to presenteeism in the workplace. It happens because migraines may occur too frequently for migraineurs to push back deadlines for each attack. The migraine is still likely to reduce productivity and become exacerbated by problematic lighting conditions in the individual's workspace.

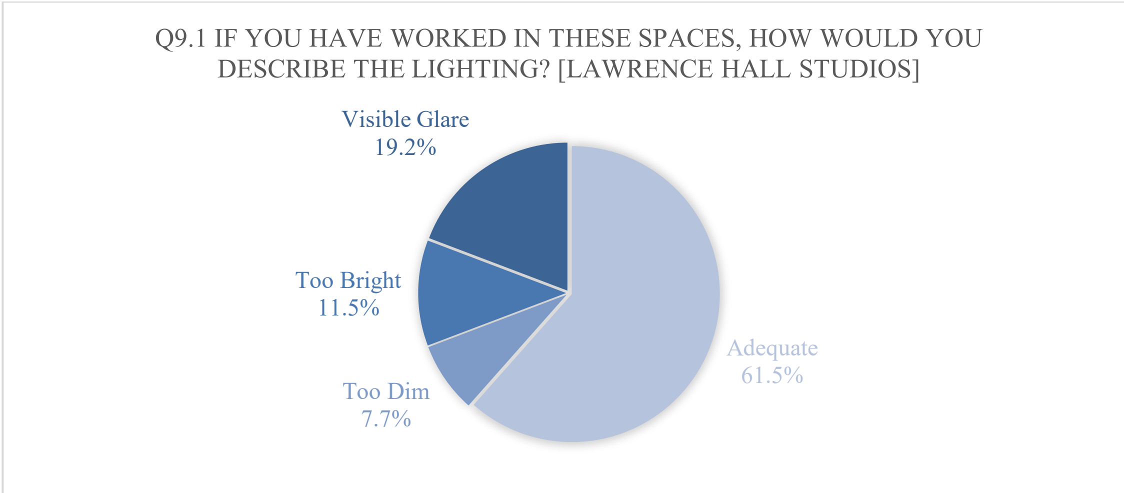


Figure 16: Survey Responses to Lawrence Hall Studio Lighting Quality

Distribution of responses to question 9, part I. Blank responses were excluded. Note 7.7% of respondents that rated the lighting in Lawrence studios did not report working in these spaces, this population considered the lighting adequate.

Participants were asked to rate the lighting conditions in both studios. The first half of question 9 asks for feedback on the lighting in Lawrence Hall. 38.5% of respondents who rated the lighting in Lawrence Hall studios gave negative feedback. The main complaint was visible glare, followed by excessive lighting, then dimness. The lack of consensus about the lighting in 4^{th} floor Lawrence studios is likely a difference in opinion and widely varied experiences due to inconsistent lighting.

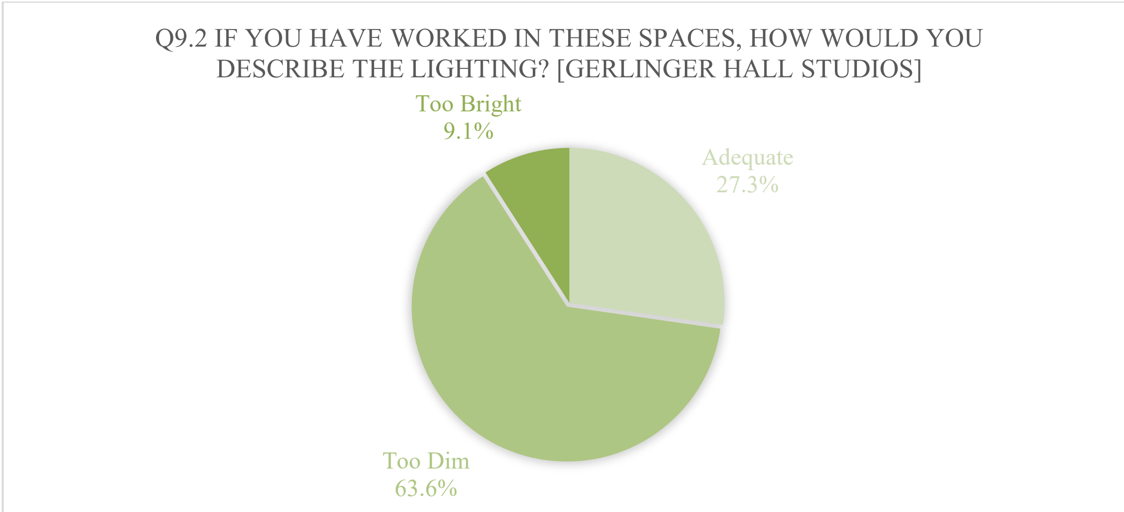


Figure 17: Survey Responses to Gerlinger Hall Studio Lighting Quality

Distribution of all responses to question 9, part II. 18.2% of respondents who rated the lighting in Gerlinger Hall studios did not report working in these spaces, this population considered these spaces too dim.

Most survey participants did not rate the lighting in Gerlinger Hall, but 72.7% of those who did offered negative feedback. The primary complaint was dimness, which is in line with the physical analysis of this space. Experiences can vary, along with opinions, but there is much more consistency in the lighting and rating of Gerlinger Hall studios. This further supports the previous conclusion that these spaces would benefit from increased illuminance.

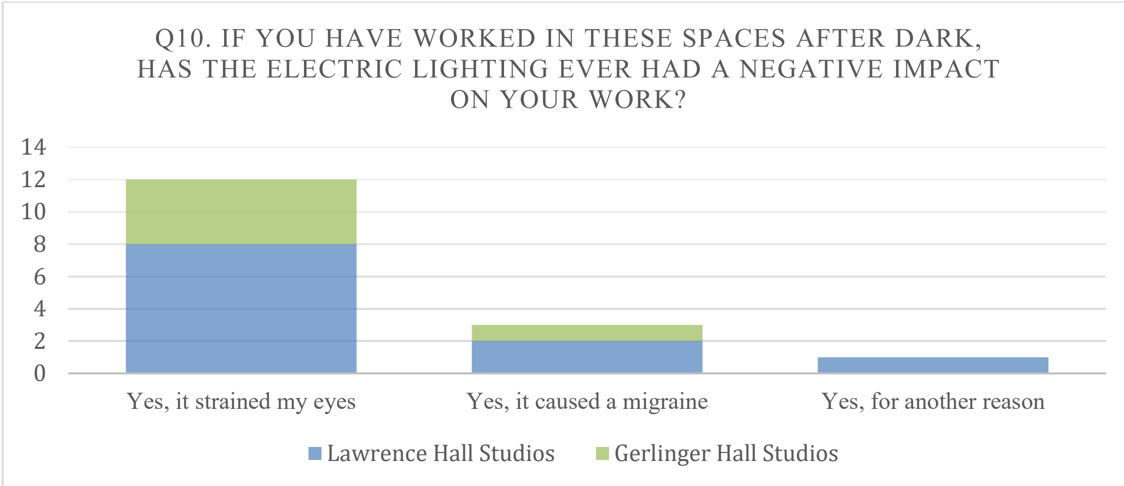


Figure 18: Reported Negative Reactions to Lighting in Lawrence and Gerlinger Hall

This chart only includes reported negative effects from Lawrence and Gerlinger Hall studios. 7.1% of people who reported ill effects from Lawrence Hall did not report working in the 4th floor studios.

Of those who answered questions about Lawrence Hall studios, 42.3% reported ill effects from those electric lighting conditions compared to 45.5% of participants who rated Gerlinger Hall. 35% of all respondents reported some negative effects from Lawrence and/or Gerlinger Hall. That is 51.9% of participants who answered questions about one or both spaces. The majority of participants have not gotten strained eyes or a migraine from studios in either building, but the lighting conditions could still worsen any headaches or photosensitivity they had before entering these spaces. The anonymous quotes offer valuable qualitative assessments that explain how participants feel about Lawrence and Gerlinger Hall studios, whether or not they have had a migraine while working there.

These spaces may rarely trigger migraines, but they have strained many users' eyes and many participants gave negative feedback. One respondent called the lighting in Lawrence and Gerlinger Hall studios "notorious," explaining that the flickering, glare, and poor lighting strain their eyes and result in painful headaches. Unfortunately, that respondent also said their productivity is hindered by pain and vision problems while working in these spaces. Another participant pointed out that the lighting varies greatly, and students adjust by turning lights on or off at different times. The ability to control workspace lighting is an asset and many shared offices do not have this luxury. However, switching the lights on and off is not enough to remove the lighting concerns in Lawrence or Gerlinger Hall. Like other workspaces, architectural intervention would be necessary to bring these studios up to idealized lighting standards.

Conclusion

Survey results are inconclusive and gave a slightly more positive picture than the measured illuminance values in Lawrence 405 and Gerlinger 143 and 144. This means spaces that fall outside an idealized lighting model may still be considered adequate by users. These spaces would benefit from lighting interventions, but they are more functional than the illuminance values alone would indicate.

There are no unanimous opinions on either Lawrence 405 or Gerlinger 143 and 144. Some approve of the lighting, but many respondents pointed out problems with both lighting conditions that were confirmed by the illuminance values collected. Based on the background research for this project, neither space has ideal lighting. Lawrence 405 has a problem with inconsistent lighting and deteriorating fluorescent light bulbs. Gerlinger Hall 143 and 144 has greater consistency, but its average illuminance values are below the minimum recommended levels for a workspace.

Because these are existing spaces, it is unrealistic to propose changing the lighting schemes completely. The idealized lighting model I am proposing includes consistent ambient lighting with a set point just above 300 lux, no higher than 1000 lux, with some exceptions for daylighting. Electric lights would ideally avoid high contrast bands. Reflective luminaires that diffuse light are ideal. And fluorescent bulbs should be well-maintained to avoid unacceptable levels of flicker, which exists in Lawrence 405. Task lighting should be provided for individuals who need more light, especially in spaces like Gerlinger 143 and 144, are too dim for most users. Ideally, there would also be dimmer areas that are partitioned off, like empty meeting rooms, to grant photosensitive individuals a comfortable place to work.

Although it is harder to renovate an existing space than build a new workspace following these principles, both studios could be adjusted to improve the experiences of students and faculty. Simply replacing flickering bulbs and offering task lighting could make a substantial improvement. Installing curtains or blinds would also be helpful, especially in Lawrence Hall. An idealized lighting model does not have to be completely fulfilled for a workspace to be comfortable and functional. Making steps towards workspaces that accommodate photosensitivity can go a long way in improving individual lives.

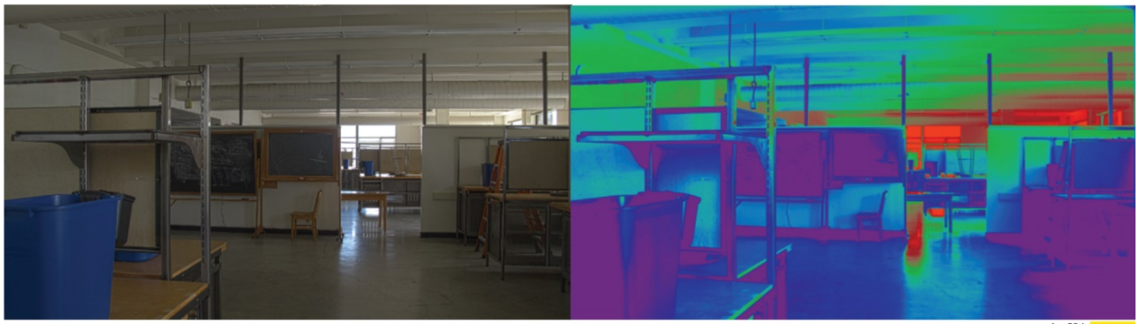
Migraines can have a devastating effect on an individual's life and work performance. However, lighting design in the workplace is rarely considered part of migraine management for the general population. Most migraine triggers are unrelated to the built environment, but lighting design should still consider and accommodate migraineurs. Designers can reduce the severity or impact of migraine attacks. This would benefit students, workers, and employers. Designers must also maintain sufficient lighting because people with aging or impaired eyes would be disadvantaged in a dim workspace. An underlit office may also lower morale and negatively impact employees' mood and mental health.

For a broad shift towards photosensitivity-conscious lighting design, both designers and clients must understand its necessity. If an architect cannot prove that every aspect of universal design is worth the extra work, it will never be funded.[87] The relationship between lighting design and photosensitivity is one small facet of design

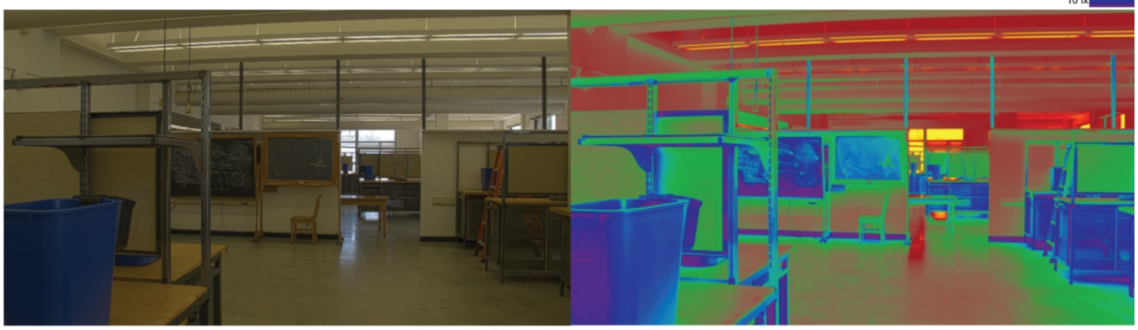
[87] Selwyn Goldsmith, *Universal Design: a Manual of Practical Guidance for Architects*, (Abingdon: Architectural Press, 2000), 14.

trends people with disabilities need to have equitable spatial experiences. Through research, persuasive arguments, and understanding audiences, designers can shape more inclusive, comfortable, and productive spaces.

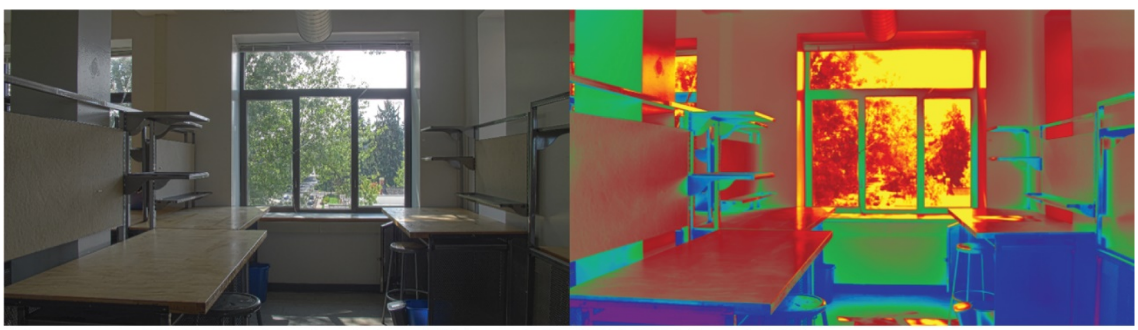
Appendix



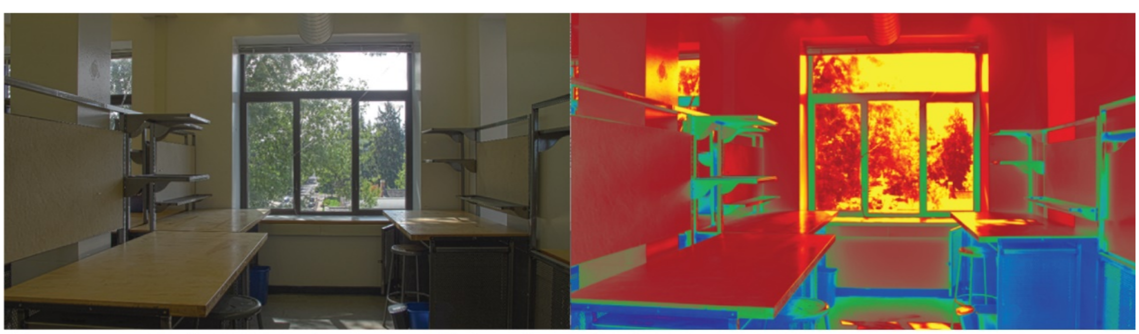
Lawrence Hall 405 Facing North, Lights Off, 9/22/2020 at 12:44 pm.



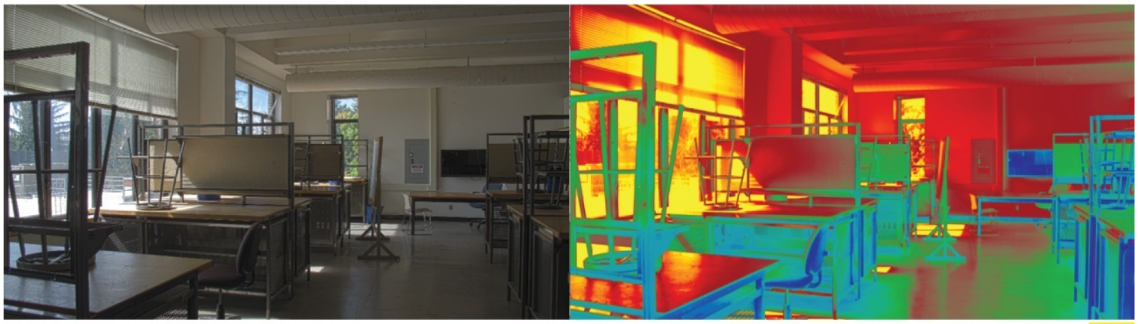
Lawrence Hall 405 Facing North, Lights On, 9/22/2020 at 12:46 pm.



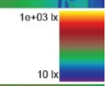
Lawrence Hall 405 Facing East, Lights Off, 9/22/2020 at 12:33 pm.

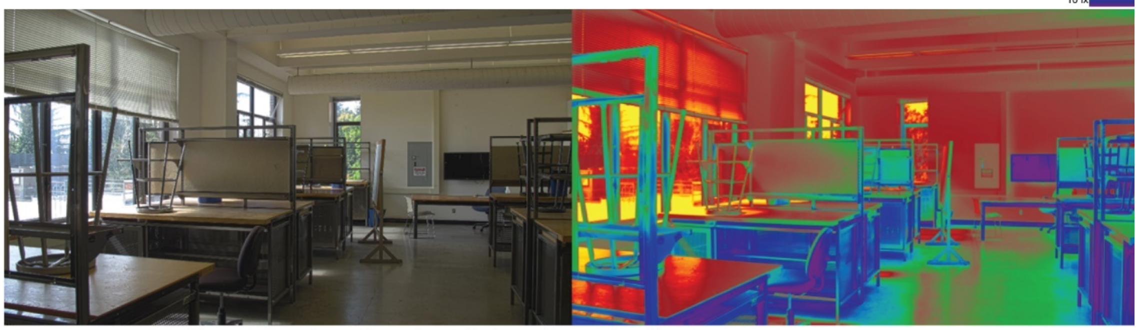


Lawrence Hall 405 Facing East, Lights On, 9/22/2020 at 12:32 pm.

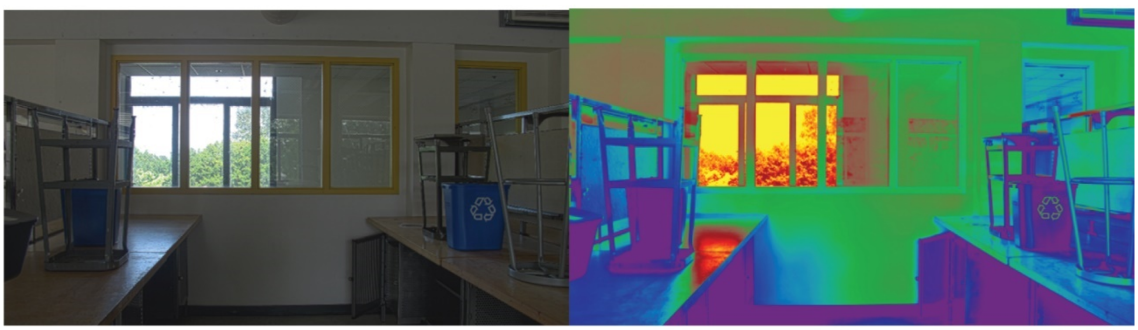


Lawrence Hall 405 Facing South, Lights Off, 9/22/2020 at 12:34 pm.

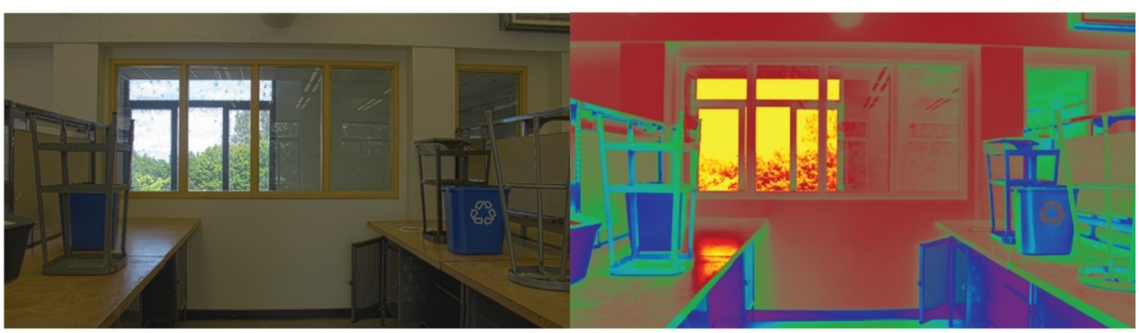




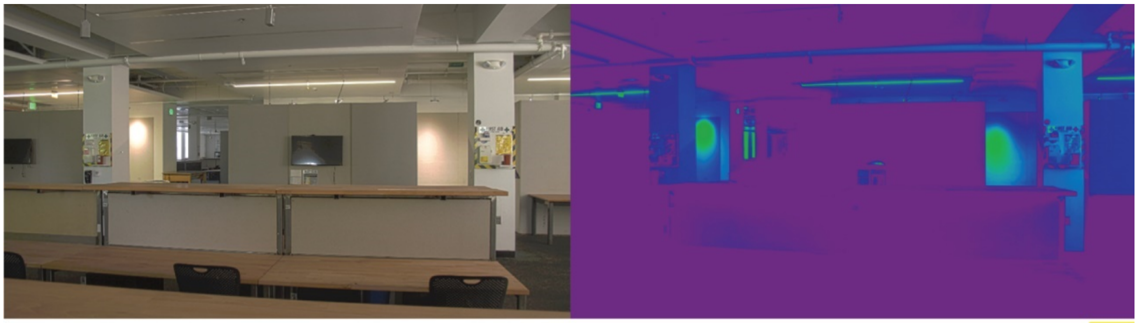
Lawrence Hall 405 Facing South, Lights On, 9/22/2020 at 12:35 pm.



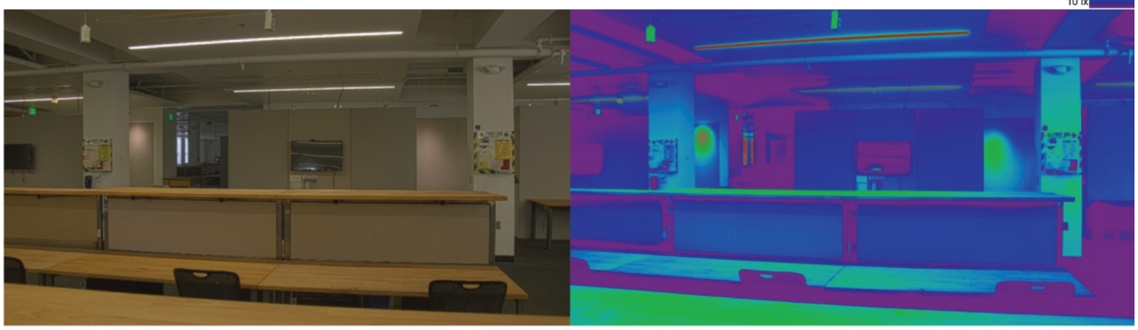
Lawrence Hall 405 Facing West, Lights Off, 9/22/2020 at 12:40 pm.



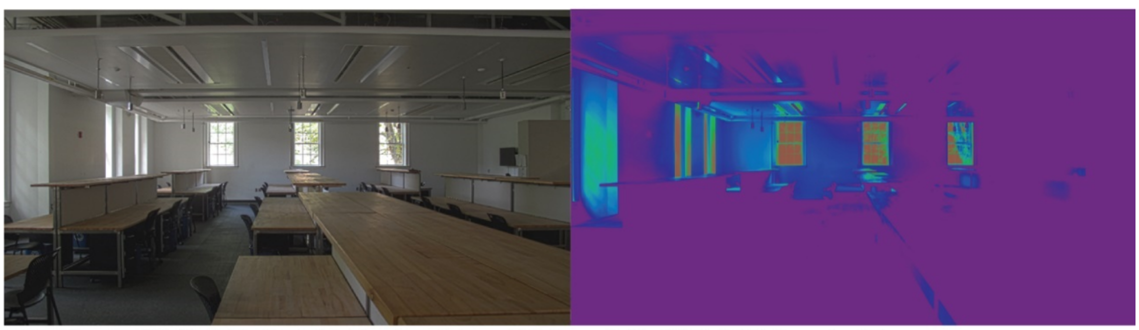
Lawrence Hall 405 Facing West, Lights On, 9/22/2020 at 12:39 pm.



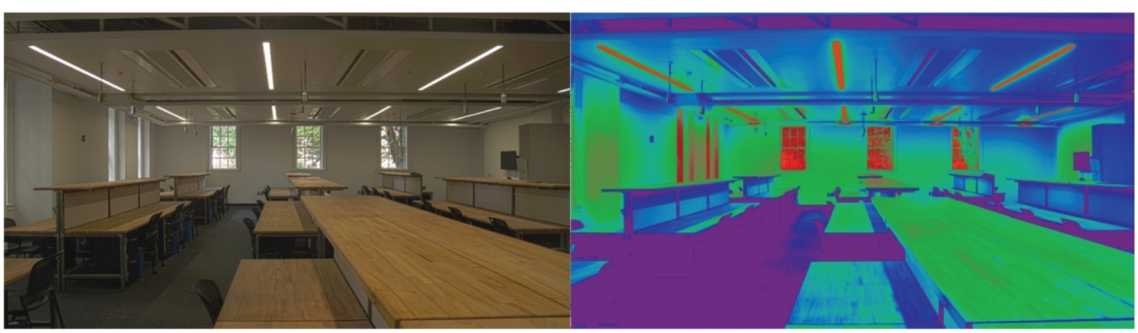
Gerlinger Hall 143 & 144 Facing North, Lights Off, 9/22/2020 at 1:33 pm.



Gerlinger Hall 143 & 144 Facing North, Lights On, 9/22/2020 at 1:35 pm.

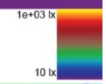


Gerlinger Hall 143 & 144 Facing East, Lights Off, 9/22/2020 at 1:45 pm.



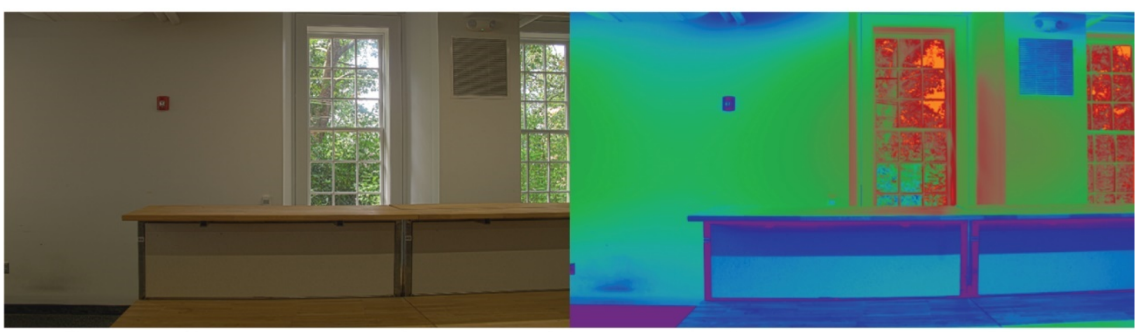
Gerlinger Hall 143 & 144 Facing East, Lights On, 9/22/2020 at 1:43 pm.

Gerlinger Hall 143 & 144 Facing South, Lights Off, 9/22/2020 at 1:38 pm.



Gerlinger Hall 143 & 144 Facing South, Lights On, 9/22/2020 at 1:36 pm.

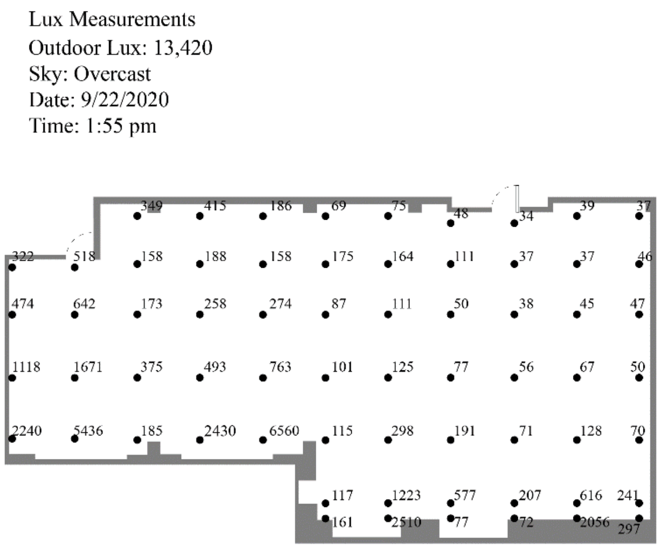
Gerlinger Hall 143 & 144   Facing West, Lights Off, 9/22/2020 at 1:39 pm.



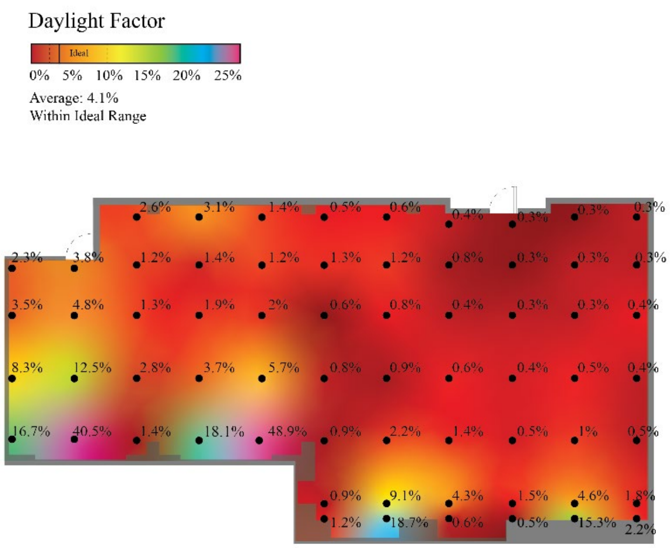
Gerlinger Hall 143 & 144 Facing West, Lights On, 9/22/2020 at 1:41 pm.

Illuminance Value and Daylight Factor Plans from 9/22/2020

These data points were measured at a different spatial interval than those used in the thesis. They resulted in the same conclusions as the other illuminance and daylight factor plans, but the exact data points do not perfectly align with the illuminance values that include electric lighting.

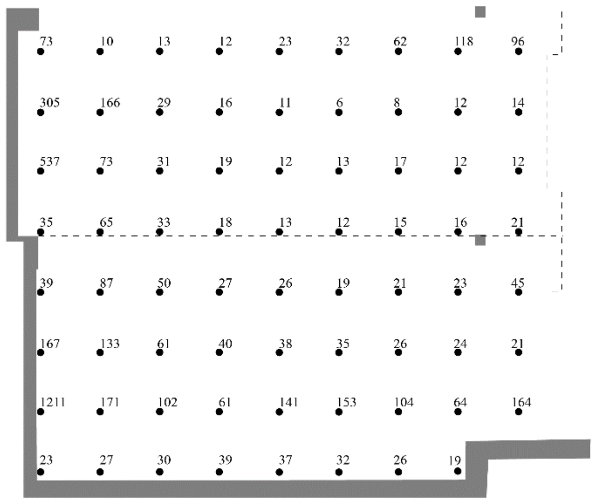


Lawrence 405 Illuminance Values



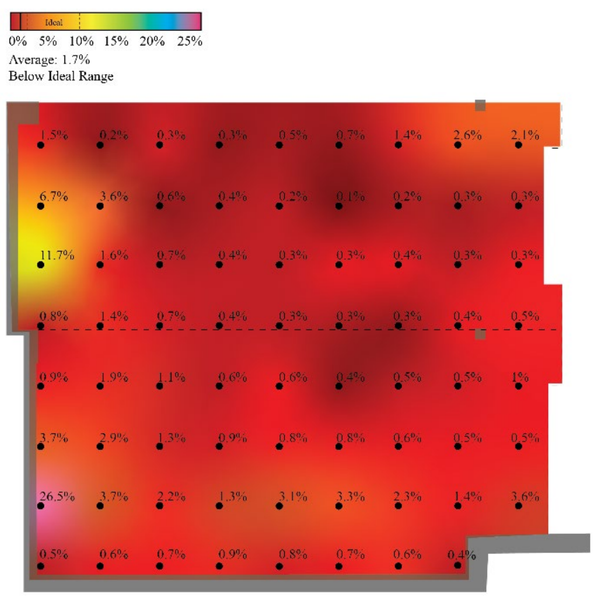
Lawrence 405 Daylight Factor

Lux Measurements
Outdoor Lux: 4,570
Sky: Overcast
Date: 9/22/2020
Time: 4:00 pm



Gerlinger 143 and 144 Illuminance Values

Daylight Factor



Gerlinger 143 and 144 Daylight Factor

Survey

0% 100%

For all research involving human subjects, it is necessary to inform participants about the nature of the research. These are the terms of this survey:

Survey responses will be support Adriann Bechtle's undergraduate honors thesis exploring the relationship between lighting conditions in workspaces and migraines. Responses from those without migraines are also helpful.

This survey has minimal risk, meaning it does not exceed the risk expected in daily life activities. No identifiers will be collected. Results will be presented as aggregate data. Participation in this survey is completely voluntary.

This survey is primarily short multiple choice questions and should take no more than ten minutes.

By selecting the text below, you are consenting to be an anonymous participant in this research project. This does not mean you are obligated to fill out the survey, it is simply required before you participate.

Please submit any questions to Adriann Bechtle at adriannb@uoregon.edu.

☐ I consent to participating in this survey.

1. What is your major/field? (Select one)

- ○ Architecture
- ○ Interior Architecture
- ○ Landscape Architecture
- ○ Other

2. What is your medically assigned sex? (Select one)

- ○ Male
- ○ Female
- ○ Intersex/other
- ○ Prefer not to say

3. What is your approximate age? (Select one)

- ◯ 18-25
- ◯ 26-40
- ◯ Over 40
- ◯ Prefer not to say

Migraines

This is a graphic to clearly explain migraines, which are distinct from other headaches.
18% of women, 6% of men, and 12% of the overall population has migraines.
Migraines may or may not be accompanied by an aura.

Source: Migraine Research Foundation

Migraine Pain Location

Usually on one side of the head and around an eye.

Illustration of Auras

Source: Migraine Canada

Often visual disturbances, such as flashes of light and/or blurred vision. Auras can also be a smell or sensation.

Other Symptoms

Dizziness
Distorted Vision
Sensitivity to light, sound, and/or smell
Nausea and vomiting
Numbness

Not all migraines are the same. They include different combinations of pain and/or associated symptoms.

4. Have you experienced migraines? (Select one)

An ocular migraine is a pulsing headache that generally focuses on one side of the head. Pain is frequently behind one eye socket and is accompanied by other symptoms such as nausea and light sensitivity. A migraine aura can occur before, during, or after a migraine.

- ○ Yes, with an aura
- ○ Yes, without an aura
- ○ No
- ○ I'm not sure, but I'm sensitive to light.

5. If you suffer from migraines, how many of them have been triggered by light? (Select one)

If you do not have migraines, skip this question.

None — All of them

0	1	2	3	4	5	6	7	8	9	10
○	○	○	○	○	○	○	○	○	○	○

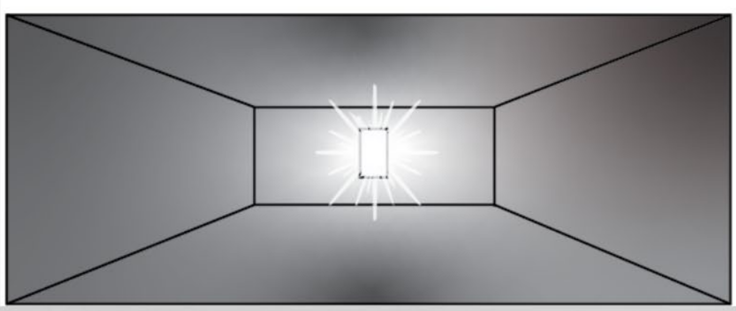
6. If you have had migraines, have they ever inhibited your school performance or attendance? (Select one)

If you do not have migraines, skip this question.

- ◯ I don't have migraines.
- ◯ No
- ◯ Yes, but not much
- ◯ Yes, it's hard to work with them
- ◯ Yes, I've had to stay home or delay work

Illustration of Glare

Glare is harsh contrast between lighting conditions, not just a measurement of brightness.
Incorrect lighting can strain your eyes, whether it's too bright, too dim, or has glare.



7. Has lighting (daylight or electric light) in your classroom or workspace ever negatively impacted your productivity? (Select one)

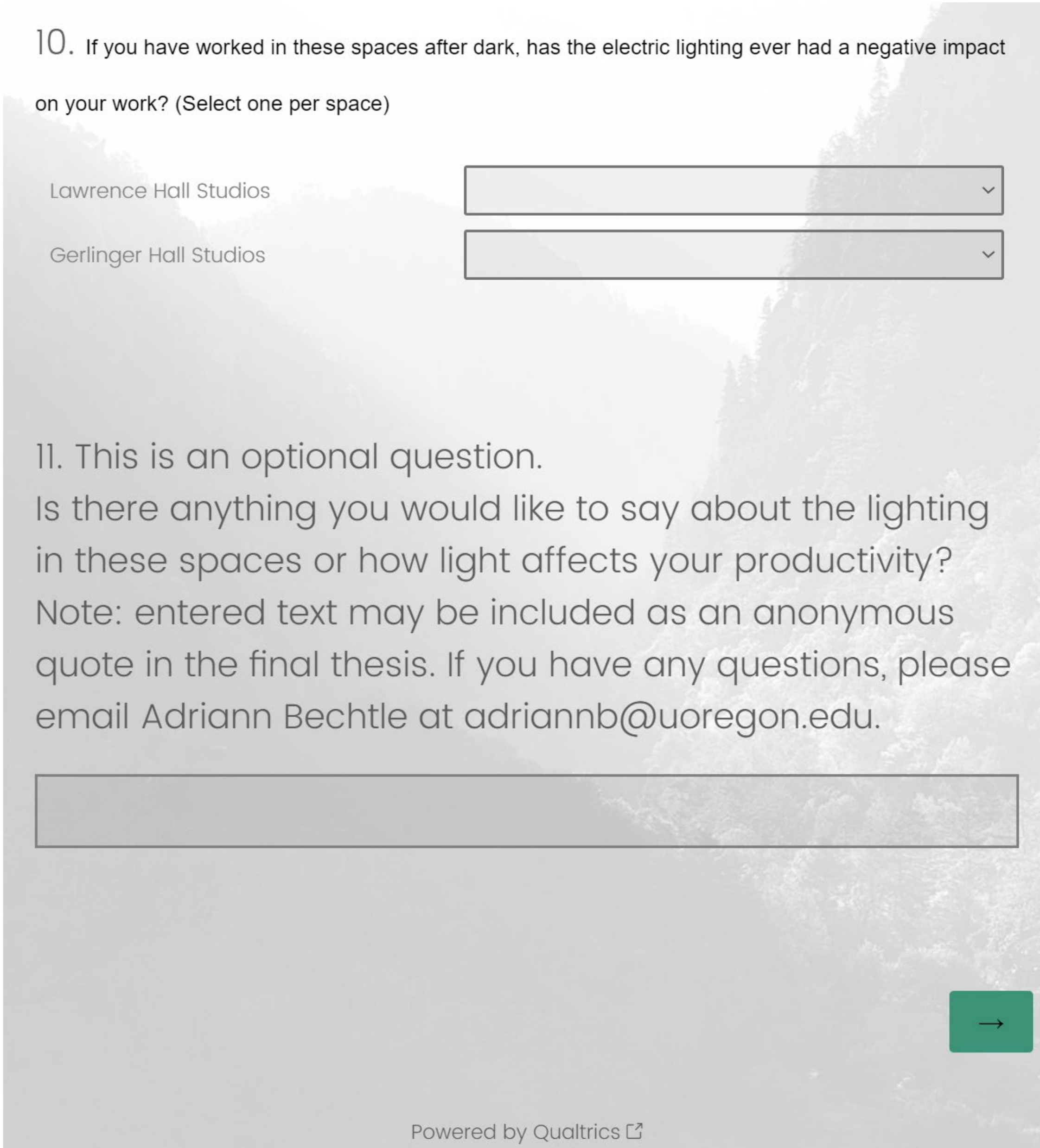
- ○ Yes, mainly due to excess light
- ○ Yes, mainly due to dimness
- ○ Yes, due to glare
- ○ No
- ○ Other

8. Have you ever worked in the fourth floor Lawrence Hall studios or the Gerlinger Hall basement studios? (Select one)

- ○  Yes, I've worked in the fourth floor Lawrence Hall studios
- ○  Yes, I've worked in the Gerlinger Hall basement studios
- ○  Yes, I've worked in both spaces
- ○ No

9. If you have worked in these spaces, how would you describe the lighting? (Select one per space)

Lawrence Hall Studios	[ ]
Gerlinger Hall Studios	[ ]



10. If you have worked in these spaces after dark, has the electric lighting ever had a negative impact on your work? (Select one per space)

Lawrence Hall Studios

Gerlinger Hall Studios

11. This is an optional question.
Is there anything you would like to say about the lighting in these spaces or how light affects your productivity?
Note: entered text may be included as an anonymous quote in the final thesis. If you have any questions, please email Adriann Bechtle at adriannb@uoregon.edu.

→

Powered by Qualtrics

Quotes from Respondents, Entered as Answers to Question 11 in the Survey

> "Natural light really improves my productivity! The motion sensor lights in Lawrence hall have been distracting and cause eye strain during long studio hours."

> "For me, Gerlinger Hall has no pleasant light and the space feels dark and dim [sic], especially the floor, in its appearance and associated material qualities."

“The lighting quality in Lawrence are not evenly distributed. Depending on where your studio desk is located, you might get a space that is too bright/dim. For me personally, our studio space is hard to adjust to personal needs of lighting, acoustics, and overall comfort.”

“The majority of the time the lighting in Lawrence is good, but in the morning (especially in east facing studios) the sun shines directly into the studios and causes a lot of glare.”

“I prefer excess natural light over excess electric lighting. I can deal with natural light much better, and even though it still triggers a migraine, it is drastically less severe than electric lighting for me.”

“When I was working in Lawrence Hall I actually had a concussion from a car accident. The light within the space was very harsh and while it was probably already a bad idea to go to studio, I definitely felt worse leaving the space. I am also prone to migraines with aura to the point where if I can see straight I just classify it as a headache, but I tried to pick desks in the middle of the classroom so there wasn't too much daylight hitting my desk and there I felt like the electrical lighting in this space was not over powering.”

“When we talk about productivity we must talk about human health and how our work space affects many hours in our day. We should be more aware of lighting design with flexibility in the functions [sic] of the lighting. We should also take into consideration lighting pollution and the power of circadian rhythm as it affects both wildlife and human cycles.”

“The lighting in both halls is notorious. Between the flickering lights, poor night lightening and ascensive daylight glare, it's a given that my eyes will feel strained and a painful headache will form. It's difficult to perform my best when I'm hindered by pain and vision problems.”

“The experience of lighting in these studios varies greatly by the available daylight in each over the course of the day, term, and year. The lights are constantly being flipped on or off to respond to daylight conditions for maximum comfort/quality.”

“Even without a migraine I still find it irritating and poor work lighting”

“Light does affect productivity. Relating to my case, I have observed that overcast sky conditions trigger my migraine. Irrespective of whether a room is lit or not doesn't impact much”

“Regarding Question 9, I would characterize lighting in the Lawrence Hall Studios according to more than one of the available options. Depending on the specific Lawrence studio space and its windows' solar aspect, the effect of glare in some situations was exacerbated by dim lighting conditions. This heightened contrast, particularly on overcast days, had a distinct effect in degrading workspace visibility.”

"The electric overhead lighting has had a big impact- especially the color or hue of the light which are often fluorescents in Lawrence hall."

Bibliography

Berry, Peggy A. "Migraine disorder: workplace implications and solutions." *Aaohn Journal* 55, no. 2 (2007): 51-56.

Demircan, Süleyman, Mustafa Atas, Sevgi ArJk Yüksel, Melek D. Ulusoy, Isa YuvacJ, Hasan B. Arifoglu, Burhan Baskan, and Gökmen Zararsiz. “The Impact of Migraine on Posterior Ocular Structures.” *Journal of Ophthalmology*, January 30, 2015.

Digre, Kathleen B, and K. C. Brennan. “Shedding Light on Photophobia.” *Journal of neuro-ophthalmology : the official journal of the North American Neuro-Ophthalmology Society*. U.S. National Library of Medicine, March 1, 2013. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3485070/.

Disability and health overview. (2020, September 16). Retrieved March 15, 2021, from https://www.cdc.gov/ncbddd/disabilityandhealth/disability.html

Figueiro, Mariana Gross. *Lighting the Way: a Key to Independence*. Washington, DC: AARP Andrus Foundation, 2002.

Friedman, Deborah I., and Timothy De Ver Dye. "Migraine and the environment." *Headache: The Journal of Head and Face Pain* 49, no. 6 (2009): 941-952.

Goldsmith, Selwyn. *Universal Design: a Manual of Practical Guidance for Architects*. Abingdon: Architectural Press, imprint of Routledge, 2000.

Grondzik, Walter T., and Alison G. Kwok. *Mechanical and Electrical Equipment for Buildings*. 12th ed. Hoboken, NJ: John Wiley and Sons, Inc., 2015.

Hauge, A.W., M. Kirchmann, and J. Olesen. “Trigger Factors in Migraine with Aura.” *Cephalalgia* 30, no. 3 (March 2010): 346–53. doi:10.1111/j.1468-2982.2009.01930.x.

International Association of Lighting Designers (IALD) + LightingEurope. “JOINT POSITION PAPER ON HUMAN CENTRIC LIGHTING.” *LIGHTINGEUROPE: The Voice of the Lighting Industry*, February 2017.

Ishii, Hirotake, Hidehiro Kanagawa, Yuta Shimamura, Kosuke Uchiyama, Kazune Miyagi, Fumiaki Obayashi, and Hiroshi Shimoda. "Intellectual productivity under task ambient lighting." *Lighting Research and Technology* 50, no. 2 (2018): 237-252.

Karanovic, Olivera, Michel Thabet, Hugh R. Wilson, and Frances Wilkinson. “Detection and Discrimination of Flicker Contrast in Migraine.” *Cephalalgia* 31, no. 6 (April 2011): 723–36. doi.org/10.1177/0333102411398401.

Lerner, D.J., B.C. Amick Iii, S. Malspeis, W.H. Rogers, N.C. Santanello, W.C. Gerth, and R.B. Lipton. "The Migraine Work and Productivity Loss Questionnaire: Concepts and Design." *Quality of Life Research* 8, no. 8 (December 1999): 699–710. https://doi.org/10.1023/a:1008920510098.

Migraine facts. (2021). Retrieved March 14, 2021, from https://migraineresearchfoundation.org/about-migraine/migraine-facts/#:~:text=Amazingly%2C%2012%25%20of%20the%20population,ages%20of%2018%20and%2044.

Mylius, Veit, Hans Joachim Braune, and Karsten Schepelmann. "Dysfunction of the Pupillary Light Reflex Following Migraine Headache." *Clinical Autonomic Research* 13, no. 1 (February 2003): 16–21. https://doi.org/10.1007/s10286-003-0065-y.

Selassie, Anbesaw W., Dulaney A. Wilson, Gabriel U. Martz, Georgette G. Smith, Janelle L. Wagner, and Braxton B. Wannamaker. "Epilepsy beyond Seizure: A Population-Based Study of Comorbidities." *Epilepsy Research* 108, no. 2 (December 18, 2013): 305–15. https://doi.org/10.1016/j.eplepsyres.2013.12.002.

Trenité, Dorothée G. A. Kasteleijn-Nolst, Alberto Verrotti, Alessia Di Fonzo, Laura Cantonetti, Raffaella Bruschi, Francesco Chiarelli, Maria Pia Villa, and Pasquale Parisi. "Headache, Epilepsy and Photosensitivity: How Are They Connected?" *The Journal of Headache and Pain* 11, no. 6 (October 21, 2010): 469–76. https://doi.org/10.1007/s10194-010-0229-9.

Vanagaite, J., Ja Pareja, O. StoRen, L.R. White, T. Sanc, and L.J. Stovner. "Light-Induced Discomfort and Pain in Migraine." Cephalalgia 17, no. 7 (April 28, 1997): 733–41. https://doi.org/10.1046/j.1468-2982.1997.1707733.x.

van Duijnhoven, Juliëtte, M. P. J. Aarts, M. B. C. Aries, A. L. P. Rosemann, and H. S. M. Kort. "Systematic review on the interaction between office light conditions and occupational health: Elucidating gaps and methodological issues." *Indoor and Built Environment* 28, no. 2 (2019): 152-174.

Webb, Ann R. "Considerations for Lighting in the Built Environment: Non-Visual Effects of Light." Energy and Buildings 38, no. 7 (April 25, 2006): 721–27. https://doi.org/10.1016/j.enbuild.2006.03.004.

Weiss, Marjorie D., Penny Bernards, and Steven J. Price. "Working through a migraine: addressing the hidden costs of workplace headaches." *Aaohn Journal* 56, no. 12 (2008): 495-502.

Wilkins, A.J. "A Physiological Basis for Visual Discomfort: Application in Lighting Design." *Department of Psychology, University of Essex,* Colchester, UK, September 2015.

Winterbottom, Mark, and Arnold Wilkins. "Lighting and Discomfort in the Classroom." *Journal of Environmental Psychology* 29, no. 1 (2009): 63–75. https://doi.org/doi.org/10.1016/j.jenvp.2008.11.007.

Yenice, Ö, S. Onal, B. Incili, A. Temel, N. Afşar, and T. Tanrıdağ. "Assessment of Spatial–Contrast Function and Short-Wavelength Sensitivity Deficits in Patients with Migraine." *Eye* 21, no. 2 (February 3, 2006): 218–23. https://doi.org/10.1038/sj.eye.6702251.