A POST-OCCUPANCY EVALUATION OF DAYLIGHT PERFORMANCE IN CLASSROOMS AT RIVER ROAD ELEMENTARY SCHOOL FOR OPTIMAL VISUAL COMFORT IN CLIMATE ZONE 4 C.

by

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THESIS ABSTRACT

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Title: A Post Occupancy Evaluation of daylight performance in classrooms at River Road Elementary School for Optimal Visual Comfort in Climate Zone 4C.

Daylight is a multifaceted phenomenon that influences occupant comfort through its dynamic visual attributes. In an exploratory study conducted at River Road Elementary school, classrooms facing north, and south are selected for visual comfort analysis. Semi-structured interviews and simulations are conducted to determine the subjective perceptions of visual comfort. While the interviews examine the teachers' perception/behavior, the simulations explore and assess selected architectural parameters that affect daylight-driven circadian lighting in the classrooms. A key and follow-up question are explored: (1) How does the post-occupancy adaptation of classrooms performed by the teachers affect their visual comfort needs during teaching hours? (2) Is there a significant discrepancy between the design and perceived illuminance levels in the North and South-facing classrooms? The key findings indicated that: (1) there is a low level of satisfaction with the perceived illuminance during teaching hours, (2) the adaptations minimized the potential for daylight to provide circadian entrainment, and in conclusion, (3) the overall pattern of visual and biological responses to light raise relevant design questions regarding perceived brightness, control, and space. To attain visually desirable environments, designers must understand daylighting strategies, shading, and the corresponding perceptions of comfort, as there can be implications on the levels of control and view quality from the window apertures.

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Dedicated to my sister Noelyne Leni Alitema, and my son Jaeden Randall Ayiko.

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I. CHAPTER I: INTRODUCTION

1.1-Background

Daylight design strategies have been actively adopted to focus on light's impact on health and promote the occupants' visual comfort in buildings. With the growing use of more oversized windows in school buildings to allow more natural light and views, it has become clear that excessive sun penetration can cause potential occupant discomfort issues. According to Day et al. 2019, a well-designed space requires balancing at least eight factors. These factors include: (1) ensuring sufficient daylight is available to perform tasks; (2) distributing daylight evenly throughout the space to prevent underlit areas; (3) minimizing glare; (4) ensuring adequate daylight illuminance for regulating electric light levels so that energy is conserved; (5) providing appropriate circadian stimulation for occupants; (6) providing outdoor views; (7) limiting glazing area; and (8) minimizing solar heat gain (Futrell et al., 2019)

Classroom lighting has been the subject of numerous studies for several years. Although daylight studies have advanced, the literature is still rich with evidence of visual discomfort. Current daylight design standards focus on providing sufficient illuminance on a work surface for various tasks and maximizing visual comfort through glare control (EN 2019; IES 2013). Since teachers spend a significant amount of time in classrooms, it is crucial to identify the gaps in daylight research for optimal visual comfort. Ideally, a thriving daylight environment should encourage learning by introducing interactions, expanding knowledge, reflecting curriculum requirements, and promoting interactions between students, teachers, and learning objects. According to Elzeyadi, 2018, best practices in K-12 school daylight design face challenges in achieving and maintaining occupant satisfaction. No matter how sophisticated the approach to daylight design, success relies on providing a satisfactory occupant experience (Day et al., 2019). For occupants to experience comfort, a level of individual control has shown significant must be established, especially in accessibility and capacity to adjust the blinds, light shelves, or lights through positional, mechanical, or interface interactions with the interior environment. Unfortunately, most challenges in a classroom setting are related to individual users' control, perception, and comfort levels. For example, according to Lang (2002), teachers prefer to control classroom lighting levels.

This premise is attributed to the adaptations to daylight during teaching hours, as will be demonstrated in this study. A crucial area of study regarding visual comfort is circadian entrainment. Circadian light relies upon the spectral quality and intensity of light entering the eye, timing, duration of exposure, and photic history (Figueiro et al. 2008). Therefore, there is a need to evaluate whether effective daylighting design according to today's daylighting standards, recommendations, and best practices (DiLaura et al. 2011; EN 2019; IES 2013) suffices to provide effective circadian entrainment. By embracing a systemic approach to design, occupants can achieve optimal health and visual comfort.

ASHRAE guidelines (ASHRAE, 2010) state that humans spend about 80–90% of their time indoors, and studies have linked comfort and health-related effects to building characteristics. The objective of this study is to evaluate the post-occupancy adaptations for optimal visual comfort. A framework is established for simulating and analyzing daylight-driven photopic and circadian illuminances within selected classrooms at River Road Elementary school. This research is a continuation of work that may help designers more effectively utilize daylight to provide visual stimulus to the occupants in a classroom environment.

This background motivated me to explore daylight performance in classrooms with the following outcomes in mind:

1. To determine a set of daylighting design parameters for the classrooms.
2. To define best practices that regulate the adaptations in these classrooms.
3. To explore the correlation between design daylight performance and the actual performance once occupied.

A summary of the research findings is provided in the following chapters. Chapter 2 includes a literature review on occupant perceptions, visual comfort, and circadian rhythm relative to numerous studies on daylight performance. The methodology of the study is described in Chapter 3. Data analysis and findings related to the research questions are summarized in Chapter 4. Lastly, chapter 5 concludes the research study and discusses the limitations.

1.2-Problem Statement

Lighting is an active element of the educational environment, which affects the execution of all educational activities (Samiou et al., 2022). Therefore, interaction with light is a process of particular importance for an occupant's visual-perceptual system. Teachers are said to have distinct preferences about classroom lighting (Schneider, 2003); for example, (Hathaway,1983) found that some teachers preferred daylight, and Lang (2002) showed that teachers preferred electric lighting due to control over lighting levels. Therefore, it is crucial to assess daylight performance through evidence-based design. One of the main factors influencing daylighting design in schools is providing sufficient illumination levels required for a multi-functioning environment and accommodating different technological advancements in teaching (Wu & Ng, 2003). To bridge the design and actual performance gap, assessing the classroom regarding the teachers' daylight perception, circadian potential, and visual comfort is of great significance. Based on the literature, there is an intersection between circadian rhythm and visual perception, and daylight conditions may influence visual comfort.

According to several studies on visual comfort, occupants may prefer different lighting conditions depending on numerous factors. According to Fakhari et al., 2021, these parameters could be categorized into individual factors (such as age, gender, mood, and social and cultural factor); architectural properties, configurations of space, and interior design (such as the geometry of the room, window characteristics, and shading devices, window orientation, wall colors, and occupants distance from the window, and occupant's position concerning the light source; physical characteristics of light (such as the amount of light, luminance distribution, illuminance, and its uniformity, and glare); and other factors such as quality of the outside view.

It remains unclear how combinations of these factors influence circadian entrainment and visual perception. A habit based on individual perception or response to stimuli by reducing the classroom window apertures has contributed to a gap identified in this study. While it is still unknown what the cause might be, these adaptations could potentially impact the quality of light and the circadian potential in a classroom setting. A comprehensive study that involves semi-structured interviews and guided simulations is used to investigate the visual perception of daylight and the potential effects on visual comfort. Currently, there is not enough literature to determine the consequences of adaptations to window apertures and their effect on visual comfort. Addressing this gap is particularly beneficial in an educational environment with an extensive range of activities going on through the day that require multiple illuminance levels.

1.2.1- Occupant Adaptation and Perception

A great deal of interest has been shown in understanding how building occupants deal with unsatisfactory indoor conditions through behavioral adaptation. Humans are not passive recipients of their immediate environment, but continuously interact with it and adapt to it. Through user interaction with the building system and user controls, behavioral adaptations take into consideration how users adjust to changing daylight conditions. This study evaluates teacher adjustments to their classroom environments to better understand the impact it has on occupant well-being through physiological, psychological, and behavioral responses. Recent studies show that there is a positive relationship between daylight access with overall well-being. In contrast, other researchers concluded that occupants with the opportunity to adapt to their environment according to their preferences experienced less discomfort. The question asked in this study aims to identify parameters related to teacher adaptation to their classrooms in Climate zone 4C and the effect on visual comfort. Some of the different approaches to studying occupant behavior include a case study, post-occupancy evaluation, simulation, and interviews. For monitoring occupant behavior, interviews, a pilot study with onsite measurements and HDR images, and accurate simulations are the most effective methods for predicting users' response behavior based on live data. Daylight and glare metrics to provide visual comfort will be assessed in this study. Evaluating the effect of the teacher's behavior depends on the type of adaptation strategies they prefer. To gain further understanding of their responses, daylighting performance parameters in terms of melanopic illuminance and glare probability are the areas considered in this study.

In 2012, LEED focused on the need to add shading to workspaces that are exposed to direct sunlight. In addition, Konis conducted a survey in 2012 in which the 'worst-case' model overestimated window blockage but predicted it more accurately than other models. Furthermore, the addition of posters to the classroom windows can quickly and easily control the amount of light entering the interior space. On comparing the different adaptations to direct daylight in both north and south classrooms, the teachers' satisfaction with natural daylight in both classrooms was incredibly low with some exceptions. Major research interest for further studies relates to developing better strategies that can provide visual comfort while minimizing the impact of different adaptations. It is evident that subdivided windows and shading control strategies are important steps for providing occupants comfort depending on their location. To investigate the cause of the teachers' control behavior and perception semi-structured interviews were conducted.

Research indicates that the occupants need simple shading control methods that can be managed manually. In addition, daylighting should be considered in every step of the façade design. The teachers' visual comfort could be ensured by considering direct illuminance coming into the classrooms, visual access to the outside, and teachers' position in the class and the board, by using accurate daylight metrics and methods.

1.3- Research Questions

Previous studies on the daylight performance in classrooms do not provide conclusive analysis or positive results concerning visual comfort. The relationship between visual perception and window apertures prompted this study and led to questions about post occupancy adaptations in the classrooms at River Road elementary school and the impact on visual comfort. Based on this observation, the research questions for this study are stated below.

Main Question

● How do the post-occupancy adaptation of north and south-facing classrooms performed by the teachers impact their visual comfort needs or perception in climate zone 4C?

Sub-Question

● Is there a significant discrepancy between the design illuminance levels and perceived illuminance levels in the North and South-facing classrooms?

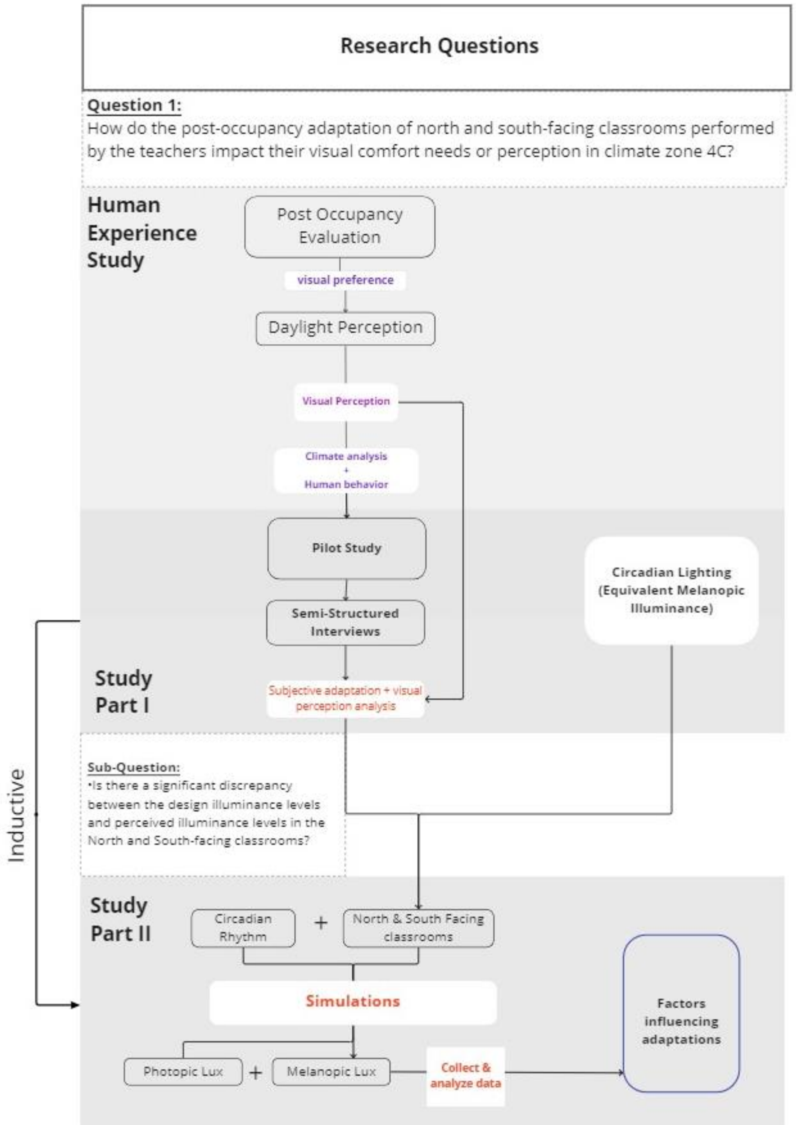


Figure 1. Research Questions and Approach

1.4- Research Objectives

This study aimed to perform a post-occupancy evaluation of daylight performance for optimal visual comfort at River Road Elementary school as a case study representing climate zone 4C. River Road elementary was part of the upgrades done by the 4J school district since the old building was considered inefficient. The newer building according to 4J school district, the light-filled two-story structure provides spaces provides better learning environments for students and costs less to operate. It is important to note that the distribution of daylight and the teachers' perception and behavior in response to the new learning environment plays a significant role in informing this study.

The teaching staff hold the most essential and direct role as guides to the processes of learning. To enhance student participation and performance, the teachers have developed a familiarity with their indoor environment and make informed assessments based on their perceptions. A huge portion of this research intends to identify daylight-related issues created because of the adaptations made to the classroom window apertures and investigate the effect of the teachers' visual perception on visual comfort. To do so, an examination of four classrooms at River Road elementary school is conducted using a comprehensive approach: human subject interviews to evaluate the post-occupancy perception of the classroom, a field study to investigate the actual daylight performance and identify any related issues, and simulations to analyze the objective metrics. This research aims to provide:

- An analysis of the tendency of individual visual behavior or perception in north and south elementary classrooms by identifying the subjective daylight conditions as observed by the teachers. The exterior conditions for the study are overcast sky conditions during spring in climate zone 4C.
- A post-occupancy assessment of the teachers' daylight control behavior, needs, and perceptions.
- The analysis of Circadian Rhythm according to the classrooms' daylight distribution and properties.

1.5- Research Significance

According to several studies, daylight has been proven to impact human comfort, emotion, and health significantly. However, many of the performance models evaluate light from a task plane rather than from an immersive perspective. It is of great significance to assess the role of daylight in classrooms to enhance the visual experience within the space and to acknowledge the effects of our circadian system. Circadian lighting is a recent phenomenon and has had limited research conducted in classrooms. To reset the human circadian clock, the predictable change in the light environment has enabled us to associate wakefulness with lit hours and sleep or rest with darkness in the built environment. Most designers encounter a known challenge in post-occupancy evaluation, especially when simulated analysis does not accurately predict the actual light environment performance. The findings of previous studies investigating the actual performance of classroom spaces do not always provide a conclusive, positive, and clear correlation between daylighting levels in these environments and student comfort (Elzeyadi, 2013). Figure 2 shows the relationship between numerous attributes of daylight stimulus as it is received by the eye or brain for physiological and psychological outcomes.

Elzeyadi & Abboushi (2019) examined the discrepancy between daylight simulation and actual daylight performance in a classroom. This research goes a step further in analyzing the post-occupancy daylight performance of south and north-facing classrooms for optimal visual comfort from the teacher's viewpoint. The teaching staff plays an essential role in indoor environmental quality control. Many studies have explored visual comfort in a classroom as perceived by the students, but there is not enough research studying the teachers' perception of daylight and visual comfort. This study aims to improve design strategies to accommodate both teacher and student activities and enhance the learning experience.

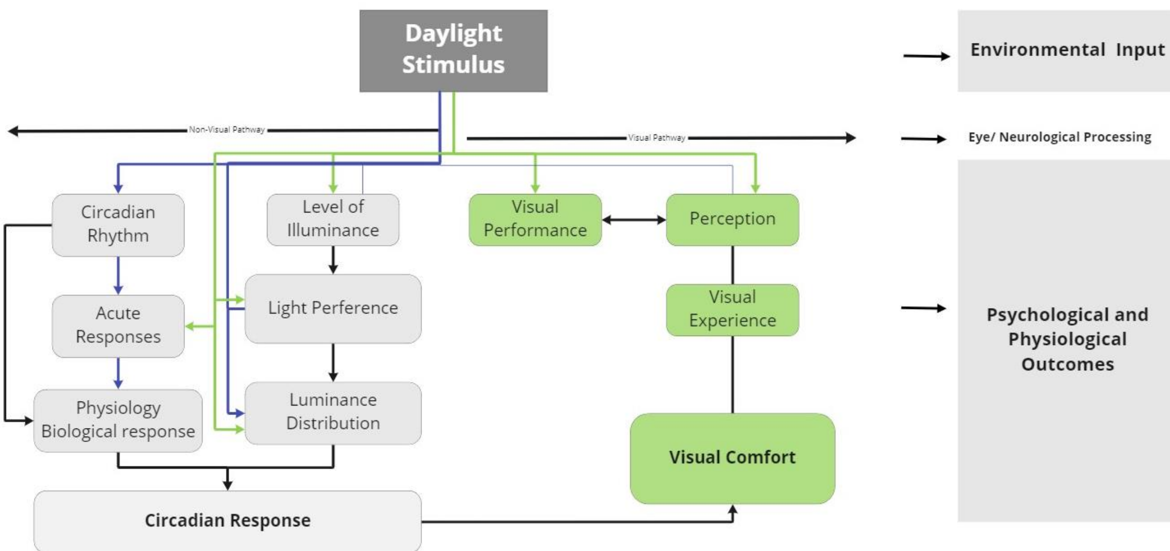


Figure 2. Relationship between Visual and non-Visual Pathways for Daylight stimulus

1.6- Research Scope

This study explores the post-occupancy adaptations to the classroom windows for optimal visual comfort in Climate zone 4.
In this research, the research is limited by:

1. **Location:** A two story classroom block which is modeled based on post-occupancy setting is documented for its daylight performance. Four classrooms are modeled as a base case and simulated for further analysis of the impact of window adaptations.
2. **Orientation:** The classrooms are north and south facing. This study will focus on four classrooms. Two north and south-facing classrooms on the first and second floor.
3. **Simulation period**: This building is simulated by ALFA-Solemma software for spring equinox (March 21^{st}). The time of day studied is adequate for circadian reset between 9 am and 2 pm.

1.7- Conceptual Framework

This research examines the daylight performance of four classrooms at River Road Elementary school for optimal visual comfort from a post-occupancy evaluation perspective. The proposed conceptual model (Figure 2) suggests that a significant correlation between the variables influences the teacher's visual preference and behavior toward daylight patterns, indicating a substantial effect on the optimal visual comfort in the four classrooms studied. As a result, when daylight enters the classroom, the teacher's visual response to various aspects, including building orientation, sky conditions, time of day, and glare, affects visual comfort. Daylight performance in a space is likely to be shaped by human perception of light, which a visual response can influence, behavioral response, or biological response to the quality or quantity of light received. Furthermore, the biological and visual responses are analyzed based on the intensity of light, perceived level of illuminance, tolerance to light distribution, window orientation, perception of glare, and circadian rhythm. These responses reflect the level of visual needs expressed by the visual perception of teachers in the classrooms, which impacts overall well-being. The diagram highlights some of the main variables examined in this research.

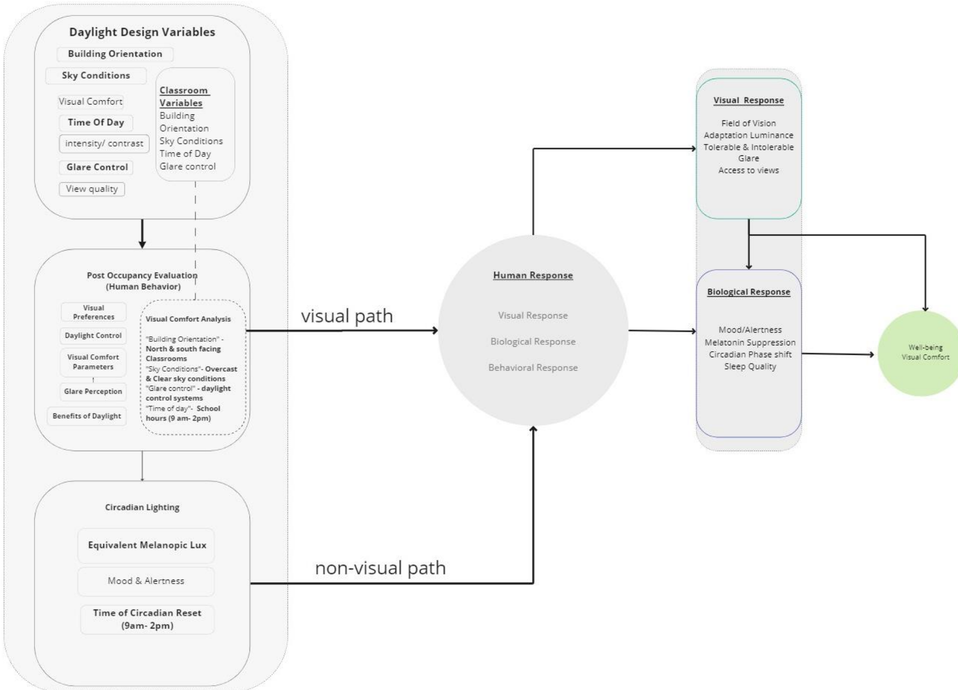


Figure 2. Conceptual Framework

1.8- Pilot Study

A post-occupancy observation and field study was carried out to document occupant responses to daylight. Five years after River Road elementary school was occupied, visual parameters and metrics were assessed and measured to provide preliminary information that would aid this study. After a brief informal dialogue with a few teaching staff members, a few concerns were brought to the forefront regarding the daylight conditions in their classrooms. The issues discussed were related to the high illuminance and solar heat loads disrupting the teacher's visual comfort in the classrooms. The preliminary investigation of the classroom daylight performance led to a pilot study of the selected classrooms in the north and south orientations. In addition, a glare analysis was carried out to understand better visual comfort conditions in the typical classroom's indoor space. From a single view position, the study aimed to evaluate the classrooms from a teacher's field of view direction at selected times of the day. This approach enforced daylight and glare analysis that depended on the light received at eye level. High Dynamic Range (HDR) images are taken with a calibrated fisheye lens specification and used to collect the luminous environment's experimental data. HDR images are typically taken at different points during user assessments to generate luminance maps of the visual environment that the user experiences, calibrated using spot luminance measurements.

During each test, bracketed image capturing sequences are continuously taken using the 'hdrscope' command line with a predetermined response function for each camera. Each HDRI is then cropped, resized to 800x800 pixels, masked, and calibrated to compute DGP indices. Finally, DGP is computed using the 'Evalglare' command. The four classrooms are north and south-facing, two on the first floor, South facing (C1), and north-facing (C2). The other two classrooms are on the second floor, and both have skylights in the classrooms South facing (C3) and north-facing (C4). Fig 4, Fig 5, Fig 6, and Fig 7 indicate the7 indicate the original HDR (left) with the corresponding luminance map (middle). The far-right images are output from Evalglare, with each separately extracted glare source shown in a distinct color.

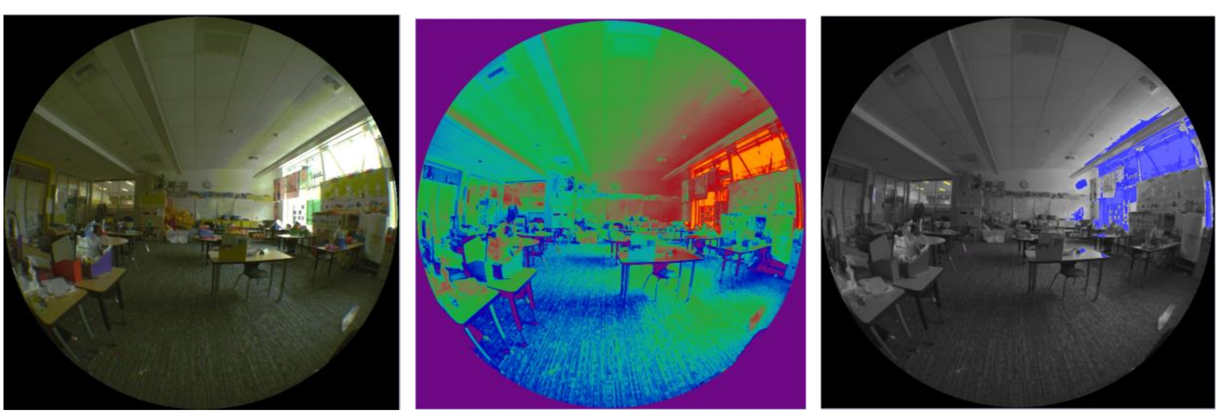
Equipment

•LiCor-210R photometric sensors to log outdoor sky illuminance levels in K-lux at 1-minute intervals

•Glare assessment and metrics are computed by employing high dynamic range images (HDRIs)

•Canon G15 camera with extra-wide angle (Opteka 52mm 0.2x HD Professional Super AF

Fisheye) fisheye lens



a. HDR Image *b. Luminance Map* *c. Evalglare detected glare sources*

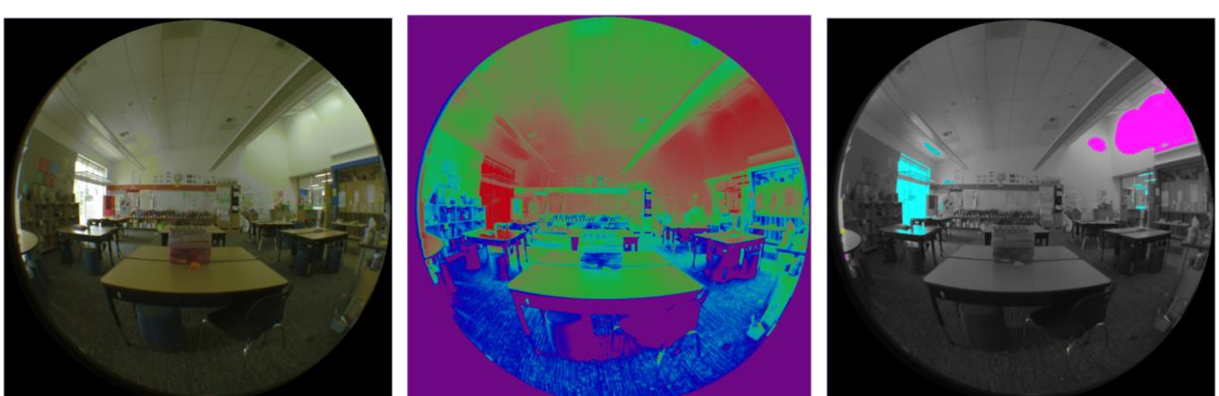
Figure 4. Glare analysis of a south facing classroom on first floor

a. HDR Image *b. Luminance Map* *c. Evalglare detected glare sources*

Figure 5. Glare analysis of a north facing classroom on first floor

a. HDR Image *b. Luminance Map* *c. Evalglare detected glare sources*

Figure 6. Glare analysis of a south facing classroom on second floor



a. HDR Image *b. Luminance Map* *c. Evalglare detected glare sources*

Figure 7. Glare analysis of a north facing classroom on second floor

Previous research has shown that Daylight Glare Probability (DGP) metrics do not accurately predict discomfort glare in some spaces in a post-occupancy evaluation setting. This finding also applies to classrooms because the deep open plan is characterized by lower vertical illumination (Ev of 300 lux or lower). As a result of the contrast between the window and low luminance levels in the room, glare was not perceived. It was challenging to use DGP metrics to justify how glare affects the space since glare was in the imperceptible range (DGP < 0.2). Fig 4-7 shows luminance maps(b) and Evalglare glare detected sources (c) from a teacher's viewpoint. Observations from the field study revealed that the classrooms are at-risk for discomfort glare, and the teaching staff has adapted to control it. To rationalize and expand on this pilot study, I moved to further the impact of daylight performance on the optimal visual comfort in each of the selected classrooms. To support my research questions, semi-structured interviews were conducted and supported by simulation-based renderings of a calibrated daylight model subjected to a level of accuracy and computational capability.

II. CHAPTER II: LITERATURE REVIEW

2.1-Daylight Analysis

Daylighting is the adequate allowance of direct sunlight, i.e., diffused skylight or natural light by providing windows and openings in a building. The primary purpose of daylighting while designing a building is to improve visual lighting transmission, thereby decreasing energy. Creating a healthy indoor environment for educational buildings is a complex process (US EPA, 2020). Different parameters affect the daylight quality of a space. The main parameters that indicate the time required to see an object are the eye's contrast sensitivity, visual acuity or sharpness of the vision, and the task's illuminance (Galal, 2019). Therefore, flicker, shadow, color perception/rendering, the directionality of the light, reflections, and glare are the parameters that affect the comfort mechanism (Galal, 2019). Chen et al., 2014, studied the daylighting effectiveness and its energy reduction potential in an industrial building through simulation software and field measurement. According to many research studies, ensuring lighting quality in an educational environment can be quite challenging. A series of different visual activities are performed within the classroom, such as reading and writing on desks and on the classroom writing boards, communication between children and the teacher, etc. (Michael et al., 2017). According to an extensive study by Heschong, (1999) elementary school students in classrooms with the most daylight showed a 21% improvement in learning rates compared to students in classrooms with the least daylight. However, the amount of daylight entering the room should not exceed the limit which would cause discomfort for occupants (Bakmohammadi, Noorzai, 2020). Daylight performance depends on the physical quantities describing the amount of light and its distribution in space, the physiology of the human eye, and the spectral emission of the light source (Bellia et al., 2021). The assessment of daylight performance per human needs includes many parameters, such as the amount of light and its uniformity, the risk of glare for occupants, the luminance distribution, and the quality of light in rendering colors (Ma'bdeh, 2019).

2.2- Visual Comfort

Daylight performance and perception in classrooms have been explored in several research papers to assess occupant visual comfort under different daylight conditions. A person's visual comfort is determined by the lighting conditions and the views from their surroundings. Visual comfort is particularly important for the well-being and productivity of the occupants of buildings (Leech et al., 2002, Serghides et al., 2015). Visual comfort depends on (i) the physiology of the human eye, (ii) the physical quantities describing the amount of light and its distribution in space, and (iii) the spectral emission of the light source (Michael et al., 2017). For humans to carry out tasks effectively, there is a need for visual comfort (Korsavi et al., 2016). To examine aspects of daylight perception in classrooms that promote discomfort and impair task performance, preference for windows and the therapeutic impact of natural views are well established in the literature (Aries, 2005). Previous studies examined daylight's influence on visual comfort across various settings. When occupants reported their long-term evaluations of visual comfort, they tended to be most sensitive to direct sunlight (Jakubiec and Reinhart 2013). Occupants experienced extreme glare discomfort when they were in the east and west-facing rooms, compared to those who were exposed to less sunlight in the north and south-facing room and had a smaller variation of luminance (Elzeyadi & Lockyear 2010). It is important to continue to expand the studies on the impact of daylight on visual comfort, particularly for education buildings. Daylight can influence visual comfort by increasing the luminance of work surfaces and/or by increasing the contrast between tasks and surroundings within the occupant's field of vision (Suk, Schiler, & Kensek, 2016). This reason makes it necessary to validate this study to gain a better understanding of daylight performance of north and south-facing classrooms for optimal visual comfort at an elementary school in climate zone 4 C. While insufficient light and especially daylight or glare reduces the ability to see objects or details clearly (Leech et al., 2002), visual comfort plays a vital role in the overall well-being of the occupants (Yun et al., 2012). Therefore, one needs to study daylight, artificial lighting, glare, and visual comfort together in order to get a more holistic picture (Van Den Wymelenberg and Inanici, 2014, Huang et al., 2012).

2.3- Human-Centric Response to Daylight

Daylight is an ideal light source to promote circadian entrainment, providing the suitable amount, spectrum, and duration for adjustment to local time (Acosta et al., 2019). Before discovering light's circadian effect, indoor lighting was thought only to provide visual comfort (Yao, 2020). There are currently no minimum requirements for daylight access in buildings to support circadian entrainment (Konis, 2017). Daylight stimulates both circadian, and acute physiological (e.g., melatonin suppression), and physical human responses (e.g., perception & behavior) (Konstantzos et al., 2020). Indoor lighting influences occupants' mood, satisfaction, productivity, and well-being (Ozcelik, et al., 2019). Thus, in this study, I investigated daylight performance as stimuli and focused on understanding human perception and circadian response to adaptations in a classroom setting. Visual and biological responses to these stimuli are being mediated by physiological and psychological responses and it takes place through human-lighting/daylighting systems interactions (e.g., switching on/off or dimming lighting, adjusting blinds, and adding posters to the classroom windows, etc.) in the classroom setting. Human-lighting system interactions could be analyzed through occupants' responses to daylight-related building elements or systems.

Most occupants prefer daylighting. Their tendency to open the blinds is because of psychological factors, while their tendency to close them is because of physiological factors (Ozcelik, et al., 2019). An occupants' lighting preference varies from one participant to another, and they need "easy to access" controls, otherwise they improvise on ways to control daylight within their spaces. Previous studies identified that user-centered controls are more crucial for health, comfort, and productivity than optimizing the pre-set conditions. In the absence of effective daylight access because of uncalculated set conditions, the occupant's circadian clock will gradually drift out of sync with the astronomical day, leading to disruption of the circadian system. In institutionalized settings, where indoor light exposures can be low, lack of sufficient exposure to bright light is one of the primary contributors to circadian disruption, with associated reported depression, sleep disruption, agitated behavior, and cognitive decline (Konis, 2018).

III. CHAPTER III: METHODOLOGY

3.1- Research Design

This study will use both quantitative and qualitative research methods, where data simulation and spatial observations will be performed at the River Road Elementary school. Parameters to be studied such as circadian rhythm (Equivalent Melanopic Lux), and visual comfort will be simulated. Because of several factors, such as a varied understanding of human behavior, time restrictions for the case study, and a sensitive user group (elementary school students), a field study will not be used for this research. The elementary school building in this case study is in Eugene, OR. The Eugene climate is classified as Climate zone 4C Marine and falls under the Csc Cold summer Mediterranean climates in the Koppen climate classification. The classroom wing of the school has both north-facing and south-facing classrooms. The selected classrooms are typical, 30' long and 31’-8” wide, with a minimum clear height of 14'0". In spring, classes are held from 9 am to 2 pm, providing insight into the simulation study. This research will employ human subject interviews to examine teacher perception and behavioral responses to daylight performance in their classrooms. To support the findings from the interviews, simulations are performed to analyze the impact of the user adaptations in each selected classroom.

3.2- Human Subject Interviews

*S*ince the main aim of this study is to assess daylight perception and control, the subject pool comprises teaching staff members who spend a significant amount of time in this environment. A qualitative interview will assess the dependent variables: participants' visual and task-oriented preferences regarding daylight perception in the classrooms (North and south-facing rooms). For the qualitative analysis of the survey results, 8 teachers are interviewed - two for each of the four orientations. The interview will take approximately 20 minutes. The interview format comprised a set of predetermined open-ended questions, and I expect that follow-up questions will emerge during the interview session. To start off the interview, introductions to the research study are made, and teachers are briefed why the interviews are a crucial part of the study. The interview format comprises a set of predetermined open-ended questions and follow-up questions that could arise during the interview session. The open-ended questions are drawn based on the aim of the study and are guided by the pilot study, literature review, and research questions. If there are questions to explore the research question, they can be added to the interview. The teachers will be asked to express satisfaction with daylight according to preference, light intensity, and quality. They will then clarify their subjective reasons for their adaptation or measures taken to control the amount of light in the classrooms. Some questions will aim to address issues related to the quantity of lighting in their rooms, the time of its intensity, and how they relate the quality of daylight to visual comfort. Finally, this study will examine the interviews to determine the parameters surrounding the post-occupancy adaptations of the classrooms. Because of IRB regulations, the interviews will be recorded, but all subjects will be anonymous, and the exact positions, age, and contact information are not recorded. The format of the interviews will be based on the subject's perception of daylight in the classrooms.

3.3- Alfa Simulation Software

Rhinoceros, a 3D modeling software, was utilized to construct the classroom geometry and then loaded to a new software plug-in to assign material with reflectance values to the model surfaces. The software measures vertical illuminance and calculates EML values. The software also provides grid-based horizontal illuminance. For this study, the simulation was conducted with daylight only. Simulations included settings of date and time of simulation, sky type, material, and sensor positions layout. The study is performed at River Road elementary school setting located in Eugene, OR (44°03′07″N, 123°05′12″W), to simulate a classroom lighting scenario. The model consists of a space with a width of 30'-8", a depth of 31'-8", and a ceiling height of 14'-0". Windows with a sill height of 2'-0" and a head height of 9'-4" are placed in the south wall of the classroom. Initial simulations of the classroom are completed to yield results that capture the full gradient of circadian illuminance within the classroom. While material spectral qualities can play a potentially influential role in the quantitative analysis of circadian light, this was not a targeted parameter being measured in this study. Materials with reflectance values typical to their location were selected from the ALFA material library for simulation. Within the classroom, model ceilings were “white painted room ceilings” with 82.2% photopic reflectance and 77.4% melanopic reflectance, walls were “white painted room walls” with 81.2% photopic reflectance and 78.3% melanopic reflectance, and floors were “interior flooring” with 38.1% photopic reflectance and 38.4% melanopic reflectance. Glazing materials used for simulation were “double IGU clear tvis 70%” with a photopic and melanopic transmittance of 70.1%. Consistent with typical daylighting design practice, the date selected for simulation was the spring solstice (March 21st). 9 am, 12 pm, and 2 pm was selected for simulation as the goal of maximizing circadian stimulus necessitates providing that stimulus during the early hours of the day to suppress melatonin production for maintained alertness throughout the day. The hours between 9 am and 2 pm were selected specifically as this corresponds with the targeted time from the WELL building standard (International WELL Building Institute 2019).

To be more concise with data collection, only spring results are provided in the paper. Cloud cover conditions were selected to reflect the weather for the selected days in Eugene. Intermediate and mostly overcast conditions in Eugene are most common during spring. Simulations for each classroom included a set of shared static base parameters including the date and time of simulation, sky conditions, and material selection. Results from the simulations were then post-processed to create visualizations and analyze the data.

3.3- Classroom Characteristics

Assessing the quality of view was part of the main aim of this research. Therefore, the authors tried to select classes with the same view but with different angles of view. Four classes, two facing south on the first & second floor (Class 1 & 2), and the other two facing north (Class 3 & 4) as shown in figures 8 & 9 were selected for this study. Although the four classes share a similar footprint and have a depth of 31-8”, there is a major difference in the window adaptations of each classroom based on each teacher’s daylight perception. Each window adaptation is a response based on several factors. The rooms are on the south side facing the school playground and have no obstacles or reflective surfaces in front of them.

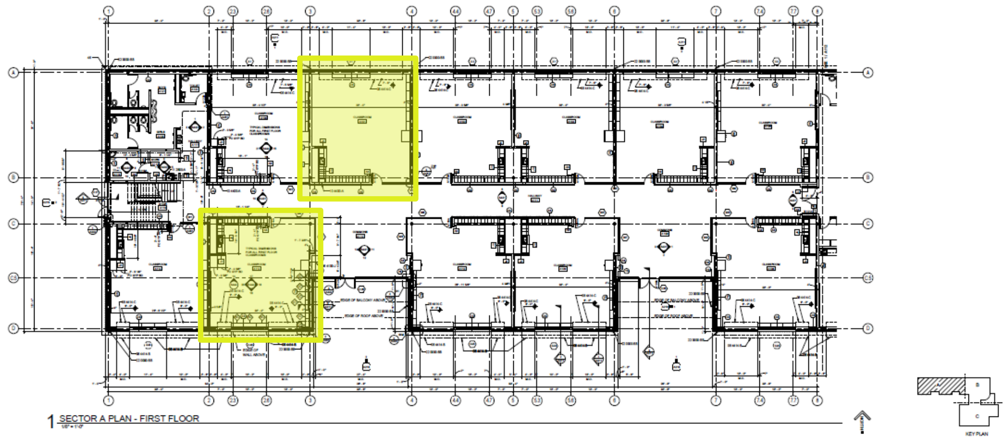


Figure 8: First Floor- Selected Classroom 1 (South) and Classroom 3 (North). (Provided by Pivot Architects)

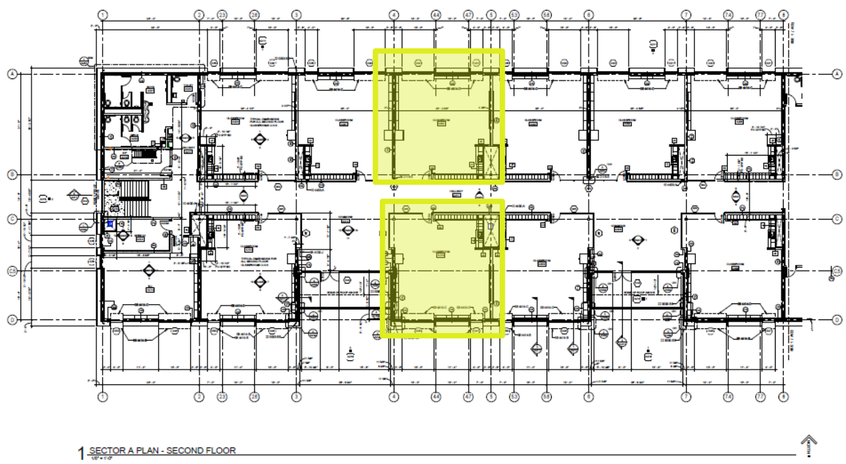


Figure 9: Second Floor- Selected Classroom 2 (South) and Classroom 4 (North). (Provided by Pivot Architects)

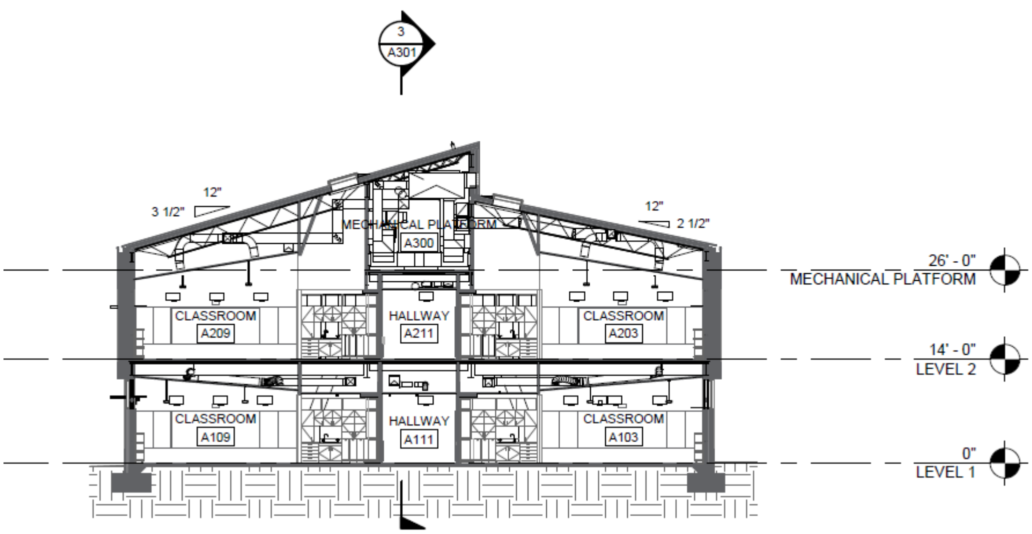


Figure 10: Building Section Classrooms (Provided by Pivot Architects)

3.4- Eugene Oregon (Ashrae Climate Zone 4C)

Eugene, Oregon, is in the Pacific Northwest part of the United States of America, a marine climate. The climate type is considered the Goldilocks climate, in a way. It is not too hot in the summer (warmest month mean temperature < 72° F), not too cold or too warm in winter (between 27 and 65° F), has at least four months with mean temperatures above 50° F and has its dry season in the summer. On average, there are around 2,535 sunshine hours per year. Daytime temperatures are warm, specifically throughout the spring months, the afternoon temperatures are usually mild, and the nighttime temperatures frequently drop on the y spring days. In Eugene, the average percentage of the sky covered by clouds experiences extreme seasonal variation over the course of the year as shown in figure 11.

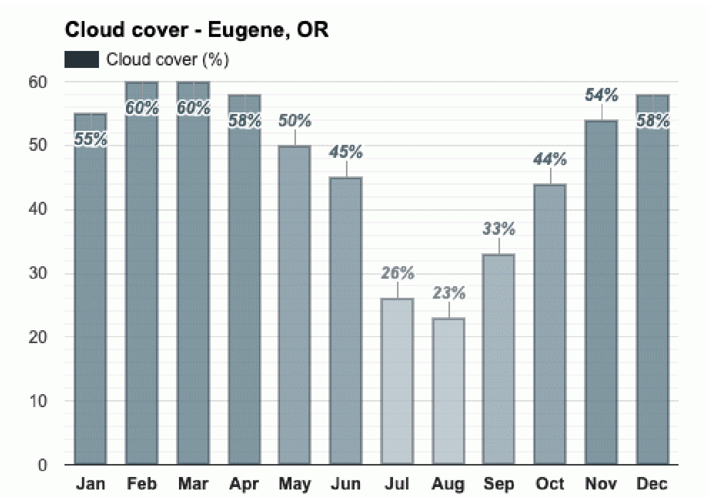


Figure 11. Annual Cloud cover in Eugene, OR

3.5- Simulation Scenarios

In this study, four different scenarios have been defined to demonstrate the different adaptation states. The base case with no adaptations added to the windows of the four classrooms, Classroom 1 (figure 12) on the south facade with partial blinds and posters on the window and clerestory, Classroom 2 (figure 13) on the second-floor south side with posters, Classroom 3 (figure 14) on the first-floor north side with full blinds down and posters on the windows, and classroom 4 (figure 15) on the second-floor north side with full blinds down. It is worth mentioning that these window adaptations have been modeled as comparable materials in the software, which are shading objects.

The performance of these classrooms will be assessed under base conditions and then with the different adaptations in each classroom as shown in figure 16. In the first stage, they will be assessed with no adaptations to understand the baseline condition, and the results could be compared with further simulations. After that, the performance of these classrooms will be evaluated. The performance of each classroom is evaluated in terms of melanopic illuminance, photopic illuminance, as well as glare for the south-facing classrooms.

Figure 12. Classroom 1- South facing on first floor with partial blinds and posters

Figure 13. Classroom 2- South facing on Second floor with posters

Figure 14. Classroom 3- North facing on first floor with full blind coverage

Figure 15. Classroom 4- North facing on Second floor with full blind coverage

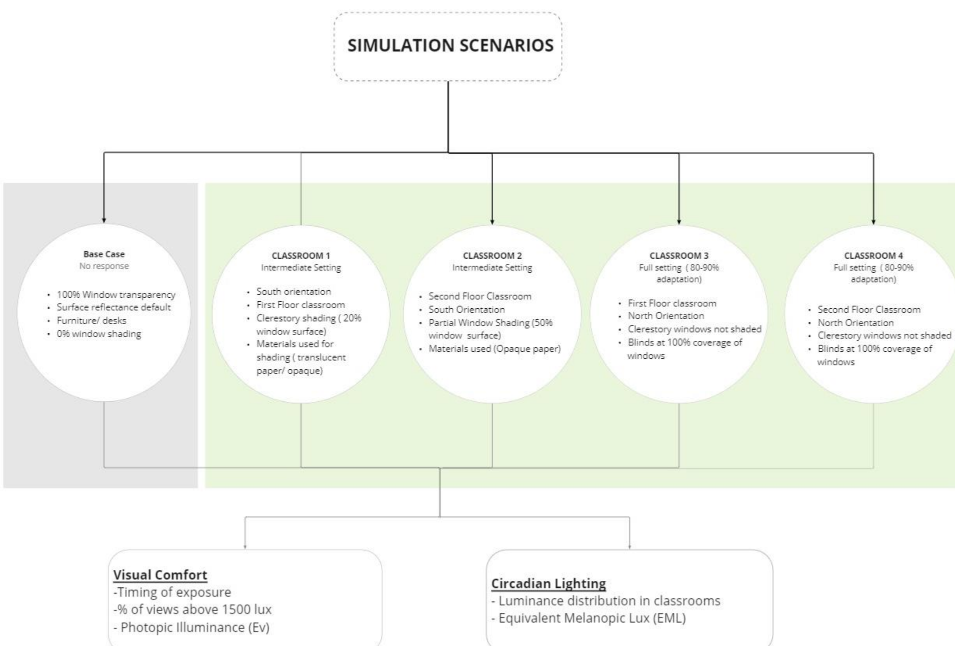


Figure 16. Alfa Simulation scenarios

IV. CHAPTER IV: DATA ANALYSIS AND DISCUSSION

This chapter presents data and findings from a post-occupancy evaluation that includes semi-structured interviews and simulation of four River Road elementary classrooms. The data collected from the simulations aims to assess daylight conditions and circadian lighting in the north and south-facing classrooms, and the interviews with the teachers, to assess perceptions on visual comfort and teaching environment satisfaction. The following sections describe the four classrooms and their associated window characteristics, the data collection methods, and the semi-structured interview format.

4.1- Analysis Of Human Subject Interviews:

An interview framework (fig. 17) showing the three different subject categories for the daylight performance of the classrooms was generated. After creating the main categories, questions and their relevance to human perception/behavior were defined. Finally, the core category was selected in a selective process to eliminate bias and imposed influence on the subject's responses. Therefore, by performing the interviews, it became possible to develop a general model that will provide information about the visual perception of teachers in the classroom environment.

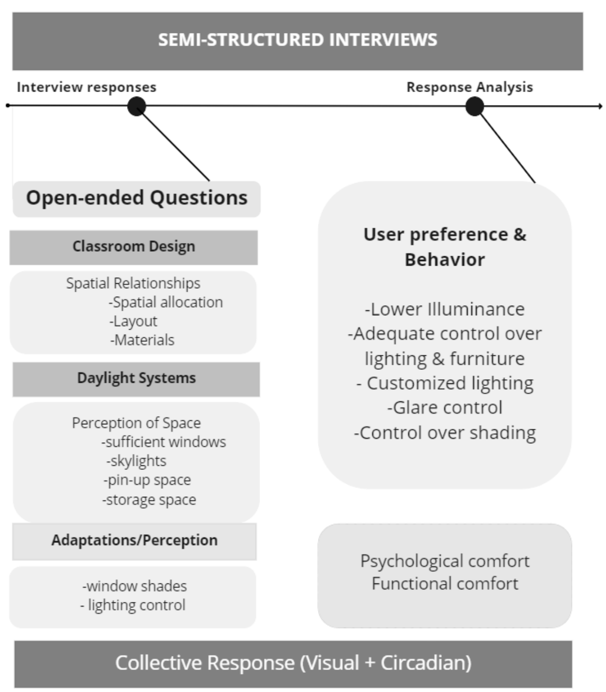


Figure 17: Interview Framework

4.1.1- Classroom Design

Spatial relationships change the visual perception and the context in which light is perceived. These factors were space allocation, layout, and materials. They impacted the teachers' comfort and, consequently, visual perception during the teaching hours. To illustrate, teachers in both north and south-facing classrooms indicated that they experienced significant brightness from the light from the windows regardless of orientation and time of day. This response was due to the lack of full control of the window shading, disrupting the use of visual display screens in the classroom. Therefore, the classroom design creates an altered perception of visual comfort in the classrooms.

4.1.2- Daylight Systems

While conducting the interviews, the teachers were asked to describe their experience with daylight in their classrooms. The use of natural light with little electric light was the most preferred in both north and south-facing classrooms. Questions regarding sufficient windows and skylights, pin-up space, and storage space were asked to investigate their adaptations further. Again, the responses varied based on personal preference, and the conditions in each classroom studied.

In addition, while the teachers agreed that they had enough control over personal space, furniture adjustability, and classroom flexibility, their satisfaction with lighting control depended on several factors, including glare control, visual connection with the outdoors, and control over window shading. To identify an ideal classroom environment, the teachers were asked a follow-up question on the control of the lighting systems; during this time, they indicated that they preferred complete control of the window shades during class. Another crucial question was whether the overall control of lighting systems was necessary. Teachers unanimously agreed on the question.

4.1.3- Adaptations/Perception

Another essential part of the conceptual model is the adaptation method. Teachers were asked to describe their adaptations to daylight during teaching hours. This question was defined by how often they operated the window shades and lighting control. It then summed up with open-ended questions that allowed them to describe their ideal teaching environment. Teachers devised adaptations to their existing situations to achieve their ideal visual comfort conditions. The post-occupancy adaptations, such as posters on the glazing area and keeping blinds down, sometimes functioned as bridges between responses and perception. An interesting result is in the approach to pin-up and storage space. Some teachers considered the lack of sufficient storage space a reason for obstructions to the glazing area.

Results show that the post-occupancy adaptations depended on several things, such as the glare sensation for south-facing classrooms, the visual preference of the teacher, the context of light sources, and the teacher's mood. Perceived visual comfort was analyzed in two subcategories, physiological (circadian rhythm) and functional (light levels) comfort. For physiological comfort, the impact of circadian rhythm is considered a reactive action as it is a natural response to illuminance levels. According to Lourenço et al., the recommended values for visual comfort parameters are restrictive, in contrast to user preferences and behavior. According to the Illuminating Engineering Society of North America (IESNA), the standard illuminance is 300 Lux, despite diverse classroom tasks resulting in multiple preferences. The teachers repeatedly emphasized that lighting conditions should be customized.

4.2- Analysis of Simulations, Ashrae Climate Zone 4C

The potential of daylight to provide circadian stimulus was assessed by comparing circadian values in the simulation models. Simulation models assessed the selection of architectural and interior parameters, including window configuration, room geometry, room surfaces, and daytime hours. A total of 24 model settings, including the base model, were evaluated for this parametric study, and collected data were isolated for each category. Additionally, the base model was assessed for the impact of daytime hours on the circadian potential of daylight during school hours. Equivalent melanopic lux (EML) values were analyzed for the identified parameters and examined to find the highest effectiveness in each parameter category. The daylight-driven simulations were completed as a series of studies isolating various architectural parameters to determine their effect on the circadian potential of the classroom. The circadian potential is the maximum percentage area in each space that daylight provides 125 EML WELL standard (International WELL Building Institute (IWBI), 2017) or more in each environment. The architectural parameters selected for further analysis in this study were: i) orientation of the classrooms, ii) adaptations to the windows, iii) building orientation and iv) shading devices. Many other factors are likely to affect the circadian potential within a space. Still, it was necessary to isolate a selection of factors for analysis in this study, as it was not feasible to evaluate for every condition. The factors selected were based on their known relevance in standard daylighting practice and the results of the early circadian analysis, which hinted toward their potential relevance in affecting circadian potential.

4.3- Base Case Simulations

The results from the daylight simulation of the four classrooms under study in the north and south orientations are shown below. Based on the Equivalent Melanopic Illuminance (EML), classrooms demonstrate almost similar performance in a base case scenario and can be characterized as well-lit spaces. Although the south-orientated classrooms indicated a higher average EML under an overcast sky, they exhibit a higher percentage of views above the 125-lux recommendation, while the lowest average EML is shown in the north-oriented classroom on the first floor. Specifically, the south-oriented classroom on the second floor meets the minimum illuminance threshold of 125 lux for 93.9% of the occupied hours in spring, while the north classroom on the second floor achieves the threshold for 97.1% of the occupied hours of the year. The north and south-oriented classrooms on the first floor achieve the threshold for 88.9% and 81.4% of the occupied hours during spring, respectively.

4.3.1- Classroom 1- South Facing Classrooms First Floor

To analyze the effects of the adaptations in classroom 1 on circadian potential, the model was simulated with a base case scenario. The results from these simulations revealed that the south-facing classroom received a significant amount of circadian lighting. Melanopic illuminance was selected as an indicator for assessing circadian effectiveness. The results indicated that at 9 am, 12 pm, and 2 pm as shown in figures 18, 19, & 20 the percentage of views above the recommended equivalent melanopic lux was 84.7%, 88%, and 94.2% which is significantly higher than the WELL recommended 75% of views above the 125 equivalent melanopic lux for circadian entrainment in classrooms.

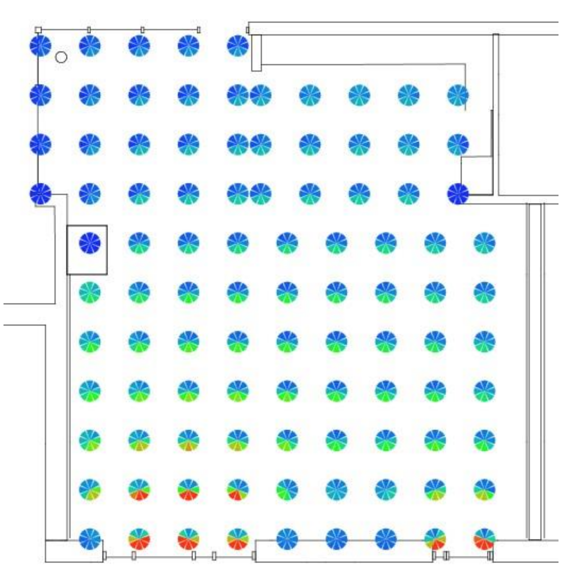


Figure 18: Base case Classroom 1- 9AM

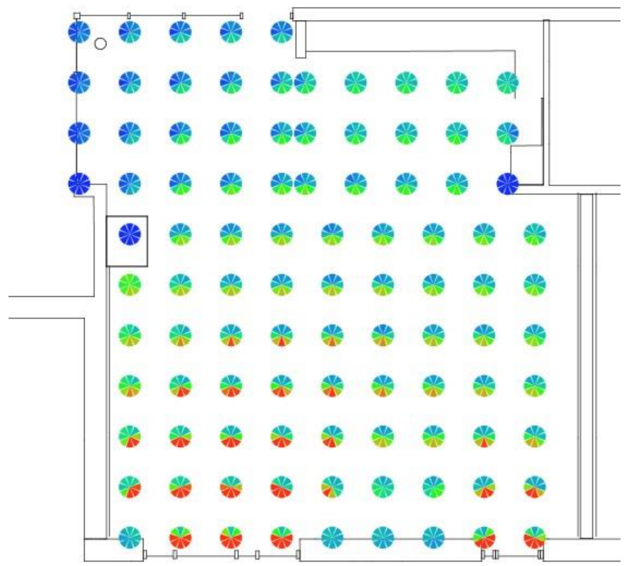


Figure 19. Base case Classroom 1- 12PM

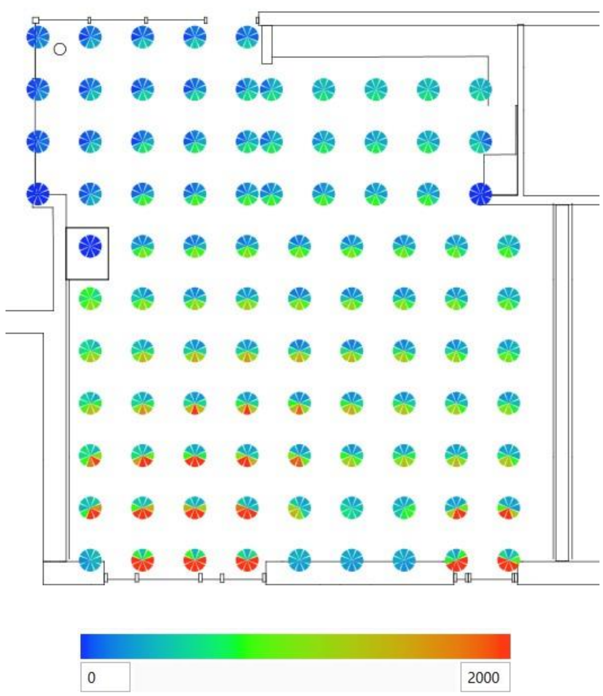


Fig 20. Base case Classroom 1- 2PM

4.3.2- Classroom 2- South Facing Classroom Second Floor

To analyze the effects of the adaptations in classroom 2 on circadian potential, the model was simulated with base case scenario. The results indicated that at 9 am, 12 pm and 2 pm as shown in figures 21, 22, & 23 the percentage of views above the recommended equivalent melanopic lux was 87.5%, 97.4%, and 97% which is well above the WELL recommended 75 % of views above the 125 equivalent melanopic lux for circadian entrainment in classrooms.

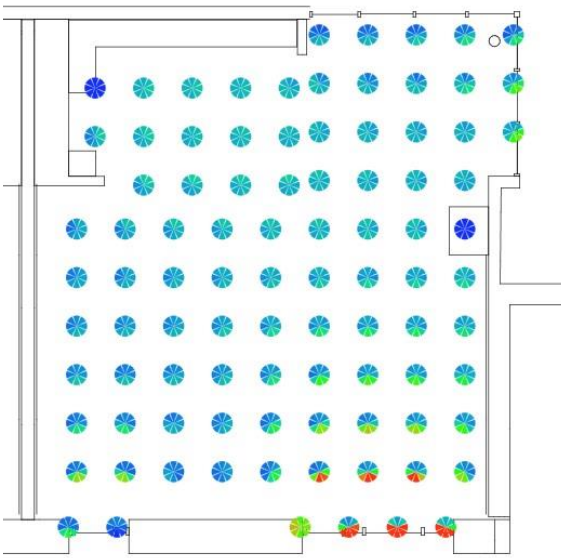


Figure 21: Base case Classroom 2- 9AM

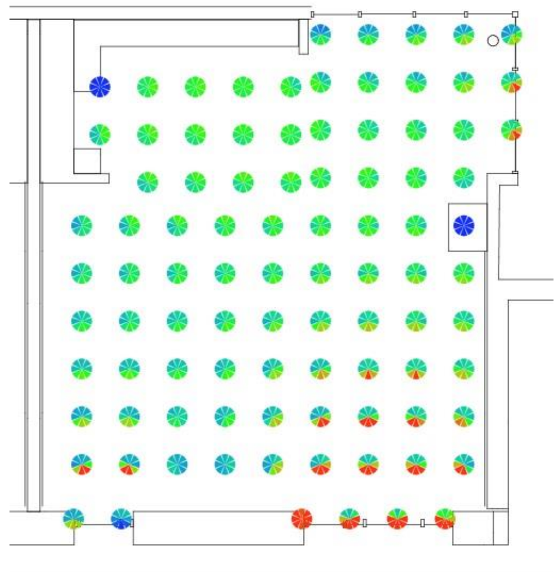


Figure 22. Base case Classroom 2- 12PM

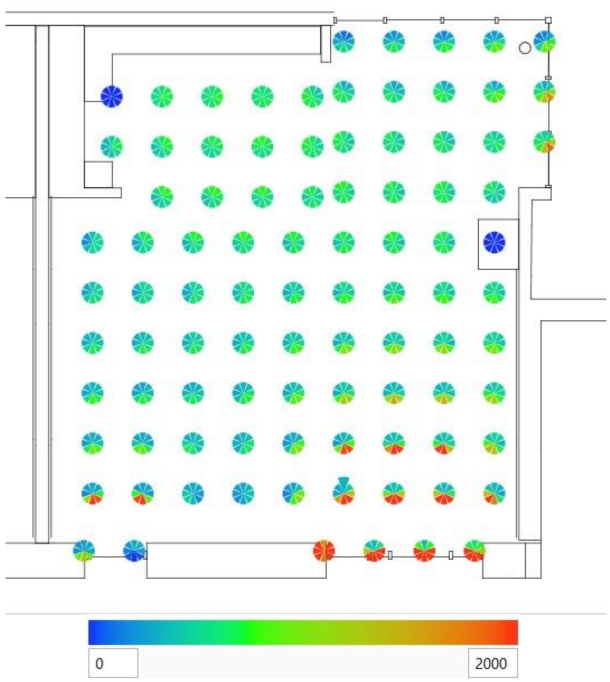


Fig 23. Base case Classroom 2- 2PM

4.3.3- Classroom 3- North Facing Classrooms First Floor

To analyze the effects of the adaptations in classroom 3 on circadian potential, the model was simulated with a base case scenario. The results indicated that at 9 am, 12 pm and 2 as shown in figure 24, 25 &26 the percentage of views above the recommended equivalent melanopic lux was 91.4%, and 87% for 12pm and 1pm which is in line with the WELL recommended 75 % of views above the 125 equivalent melanopic lux for circadian entrainment in classrooms. While 9am, was 65.2%, and below the WELL recommended of 75%. Given 9 am is a crucial learning time in classrooms in all orientations, this raises huge concerns about the amount of adequate daylight received in the classrooms necessary for circadian entrainment.

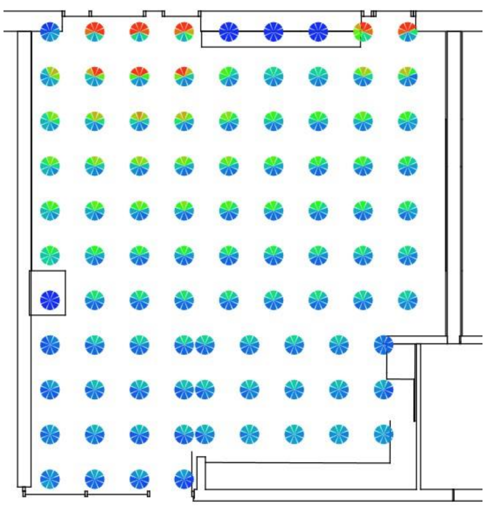


Figure 24: Base case Classroom 3- 9AM

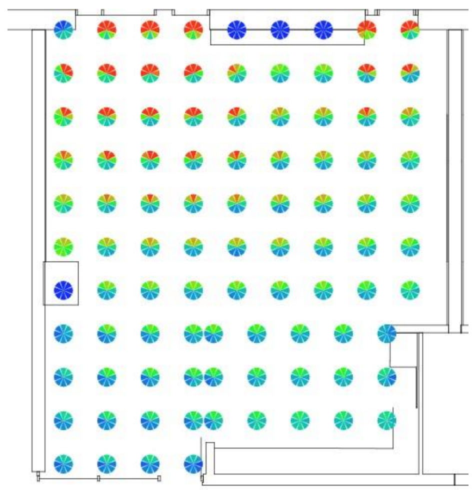


Figure 25. Base case Classroom 3- 12PM

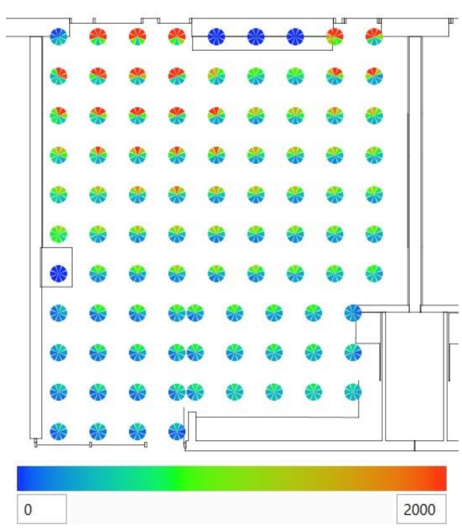


Fig 26.: Base case Classroom 3- 2PM

4.3.4- Classroom 4- North Facing Classrooms Second Floor

To analyze the effects of the adaptations in classroom 4 on circadian potential, the model was simulated with base case scenario. The results from these simulations revealed that the south-facing classroom experienced a significant reduction in circadian potential as compared to the base case. Melanopic illuminance was selected as an indicator for assessing circadian effectiveness. The results indicated that at 9 am, 12 pm and 2 pm as shown in figures 27, 28, & 29 the percentage of views above the recommended equivalent melanopic lux was 96.2%, 97.7 %, and 97.6 % which is significantly higher than the WELL recommended 75 % of views above the 125 equivalent melanopic lux for circadian entrainment in classrooms.

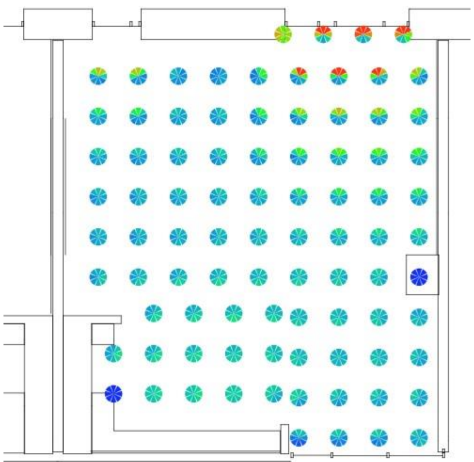


Figure 27: Base case Classroom 4- 9AM

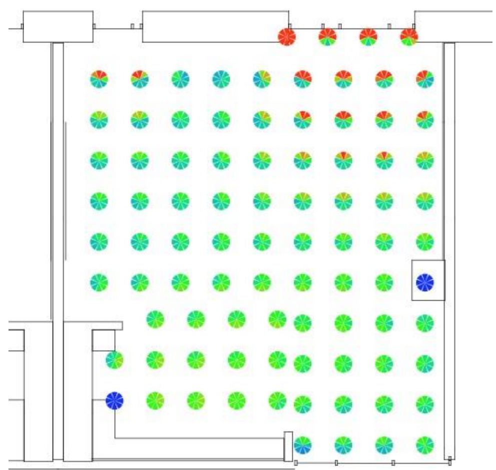


Figure 28: Base case Classroom 4- 12PM

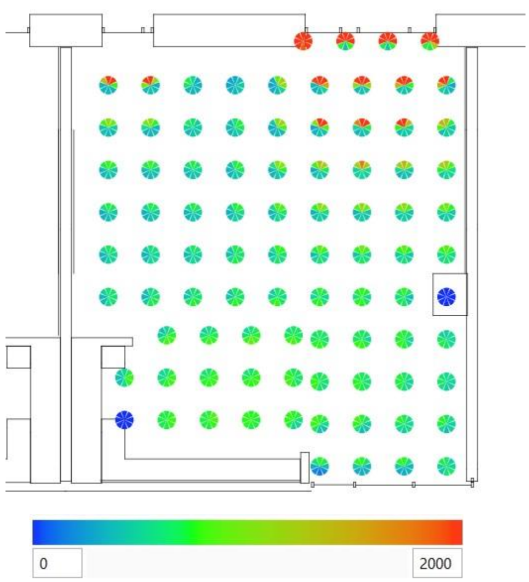


Fig 29: Base case Classroom 4- 2PM

4.4- Analysis Of Adaptations To The Classrooms

4.4.1- Classroom 1- Posters & Partial Blinds

To analyze the effects of the adaptations in classroom 1 on circadian potential, the model was simulated with posters and partial blinds added to the windows. Figure, 30, 31, and 32 indicate melanopic illuminance distribution in classroom 1. Here, we see daylight levels are insufficient for circadian entrainment, which occurs between 9 am and 2 pm. At 9 am, the average melanopic illuminance is 110 lux with the percentage of views above the recommended 125 lux being 8.9%. At 12 pm, the average melanopic illuminance is 181 lux with the percentage of views above the recommended 125 lux being 22.6%. And at 2 pm, the average melanopic illuminance is 110 with the percentage of views above the recommended 125 lux being 19.5%. The areas closer to the window receive some light around the afternoon hours. Once the classroom is set with the adaptations, the melanopic illuminance levels at all three times of the day are at an extremely low value. With conditions as dark as they are in classroom 1, daylight levels are far too low for light to be effectively used and are considered biologically dark. It is likely that occupants would not receive full circadian potential.

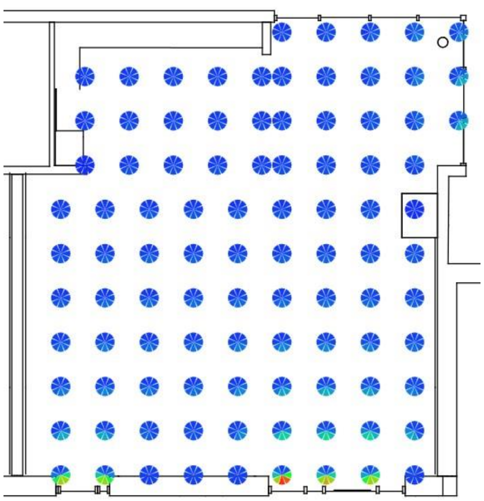


Figure 30. Melanopic Illuminance in Classroom 1 with adaptations- 9 AM

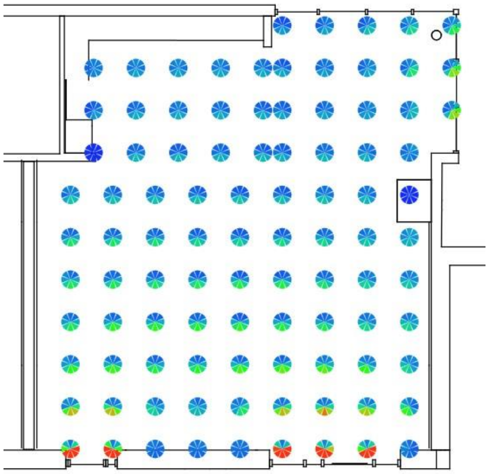


Figure 31. Melanopic Illuminance in Classroom 1 with adaptations- 12 PM

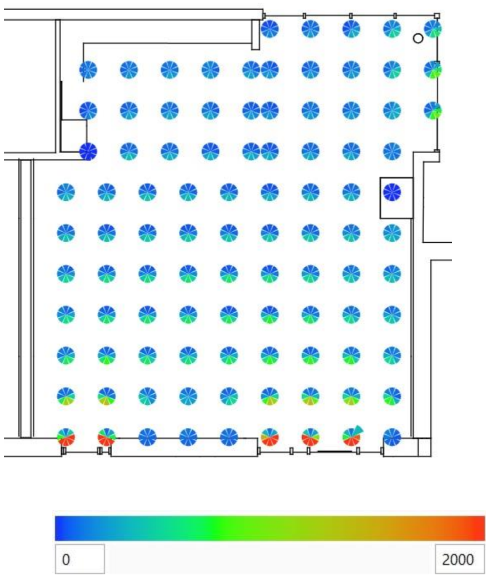


Figure 32. Melanopic Illuminance in Classroom 1 with adaptations- 2 PM

4.4.2- Classroom 2- Posters

To analyze the effects of the adaptations in classroom 2 on circadian potential, the model was simulated with posters added to the windows. Figures 33, 34, & 35 show average levels of melanopic illuminance in classroom 2. Here, daylight levels are insufficient for circadian entrainment, which occurs between 9 am and 2 pm. At 9 am, the average melanopic illuminance is 198 lux, with the percentage of views above the recommended 125 lux being 30.6%. At noon, the average melanopic illuminance is 181 lux, with the percentage of views above the recommended 125 lux being 22.6%. And at 2 pm, the average melanopic illuminance is 110 lux, with the percentage of views above the recommended 125 lux being 19.5%. While the values are still low, the classroom has the advantage of an unobstructed skylight that disperses light to a part of the room despite the modified window apertures. However, like classroom 1, daylight levels are still low for effective use of light and are still considered biologically dark. Therefore, it is likely that occupants would not receive full circadian potential.

The results also assessed the likelihood of visual comfort in the classrooms in terms of photopic lux (Ev). The percentage of views above 1500 lux for classroom 2 at 9 am, 12 pm, and 2 pm were 0.8%, 1.6%, and 1.2%, respectively. These results showed that there is obstruction of views of the outdoors and that the access to adequate daylight for optimal visual comfort was limited.

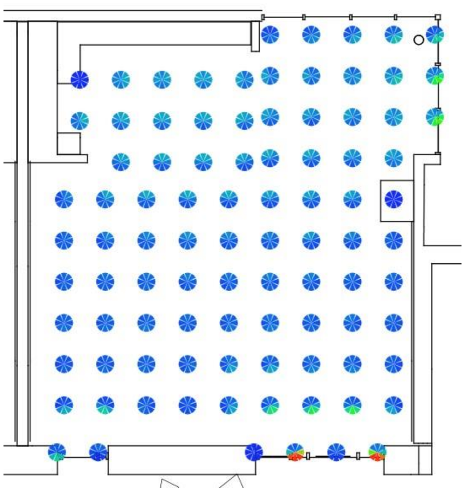


Figure 33. Melanopic Illuminance in Classroom 2 with adaptations- 9 AM

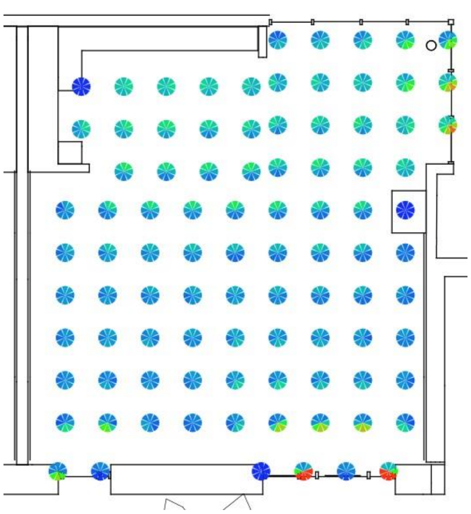


Figure 34. Melanopic Illuminance in Classroom 2 with adaptations- 12 PM

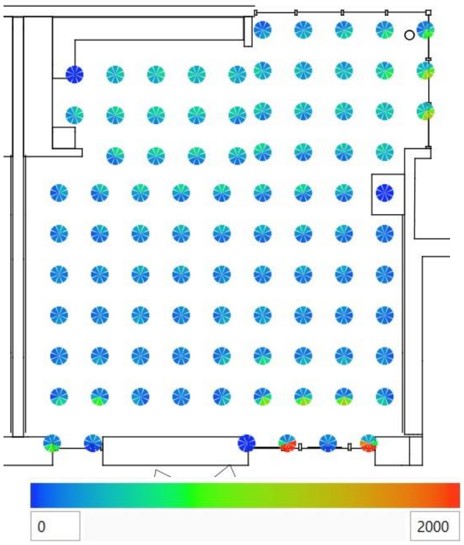


Figure 35. Melanopic Illuminance in Classroom 2 with adaptations- 2 PM

4.4.3- Classroom 3- Blinds

To analyze the effects of the adaptations in classroom 2 on circadian potential, the model was simulated with blinds fully closed. Figures 36, 37, and 38 show average levels of melanopic illuminance in classroom 3. Here, daylight levels are insufficient for circadian entrainment, which occurs between 9 am and 2 pm. At 9 am, the average melanopic illuminance is 156 lux, with the percentage of views above the recommended 125 lux being 26.2%. At noon, the average melanopic illuminance is 285 lux, with the percentage of views above the recommended 125 lux being 54.5%. And at 2 pm, the average melanopic illuminance is 252 lux, with the percentage of views above the recommended 125 lux being 44.0%. While the values are moderate for circadian lighting, they are not yet ideal for visual comfort. The classroom has an unobstructed clerestory window that lets in light throughout the day. This classroom is not considered biologically dark due to the moderate amount of light received throughout the day. While the light levels in the morning are still considered too low for circadian entrainment, the occupants are likely to receive a small amount of afternoon light that can compensate for the morning hours. The results also assessed the likelihood of visual comfort in the classrooms in terms of photopic lux (Ev). The percentage of views above 1500 lux for classroom 3 at 9 am, 12 pm, and 2 pm were all 0%. These results showed that there is obstruction of views of the outdoors and that the access to adequate daylight for optimal visual comfort was limited.

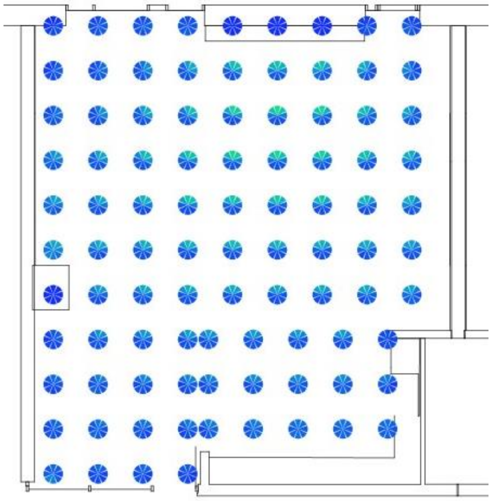


Figure 36. Melanopic Illuminance in Classroom 3 with adaptations- 9 AM

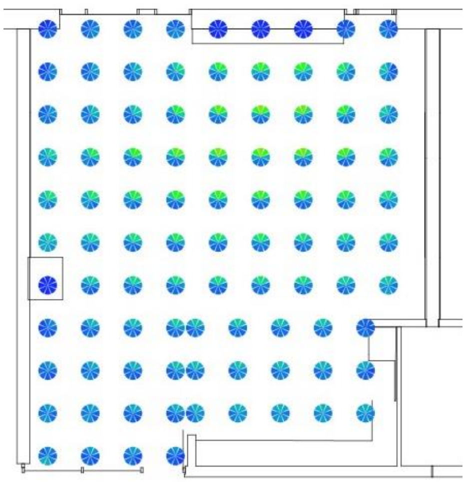


Figure 37. Melanopic Illuminance in Classroom 3 with adaptations- 12 PM

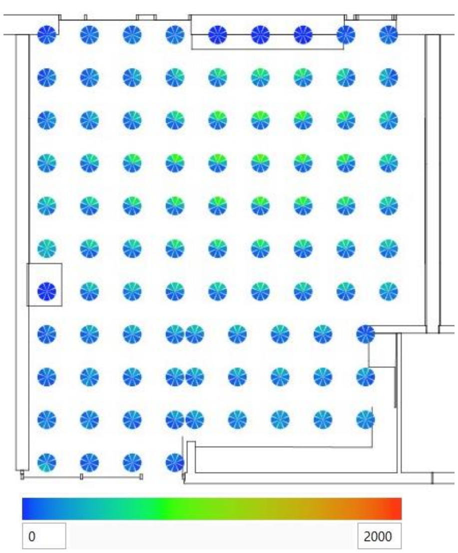


Fig 38. Melanopic Illuminance in Classroom 3 with adaptations- 2 PM

4.4.4- Classroom 4- Blinds

The simulations in Figures 39, 40, & 41 provide explanations for the impact of the adaptations to visual comfort in classroom 4 with full blind coverage to the windows. Here, daylight levels are insufficient for circadian entrainment, which occurs between 9 am and 2 pm. At 9 am, the average melanopic illuminance is 154 lux, with the percentage of views above the recommended 125 lux being 26%. At noon, the average melanopic illuminance is 337 lux, with the percentage of views above the recommended 125 lux being 82.5%. And at 2 pm, the average melanopic illuminance is 300 lux, with the percentage of views above the recommended 125 lux being 74.1%. This classroom had the ideal values for circadian lighting. The classroom has an unobstructed clerestory window and skylights letting light throughout the day. The classroom is not considered biologically dark during teaching hours due to the ideal amount of light received throughout the day despite having complete blinds down. While the light levels in the morning are still considered too low for circadian entrainment, the occupants are likely to receive a significant amount of afternoon light that can compensate for the morning hours. The results also assessed the likelihood of visual comfort in the classrooms in terms of photopic lux (Ev). The percentage of views above 1500 lux for classroom 3 at 9 am, 12 pm, and 2 pm was 0%.

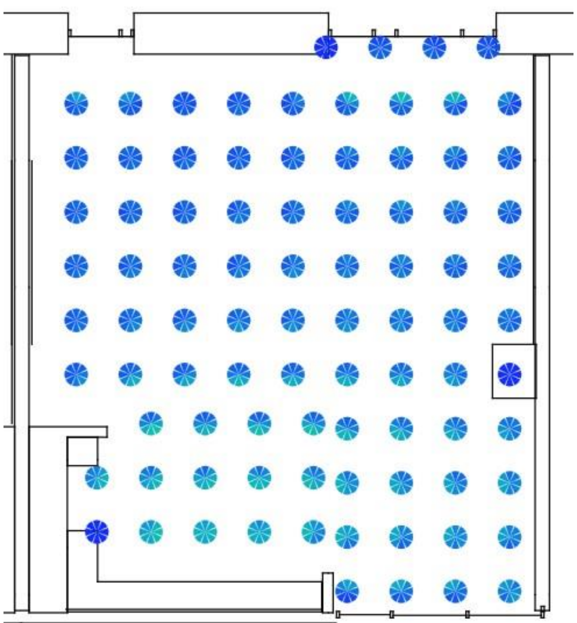


Figure 39. Melanopic Illuminance in Classroom 4 with adaptations- 9 AM

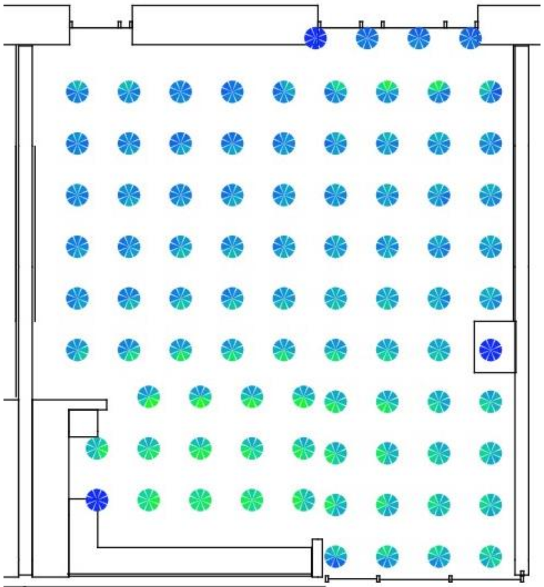


Figure 40. Melanopic Illuminance in Classroom 4 with adaptations- 12 PM

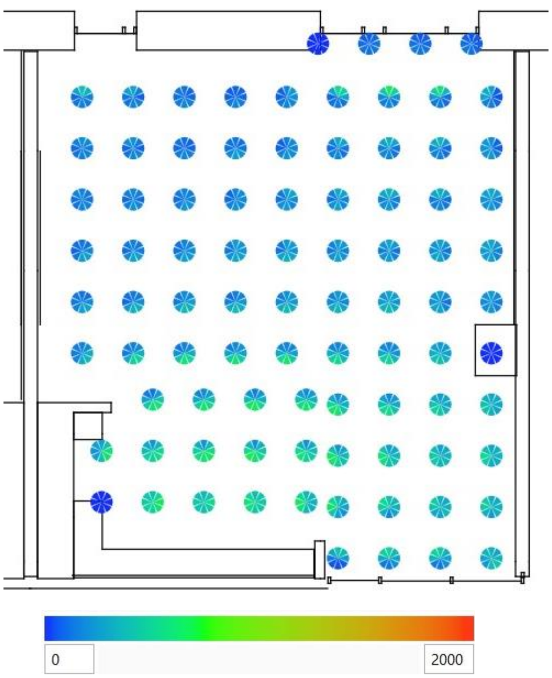


Fig 41. Melanopic Illuminance in Classroom 4 with adaptations- 2 PM

4.5- Discussion

The Circadian entrainment potential in Equivalent Melanopic Illuminance (EML) for the classrooms with adaptations was significantly lower than in the classrooms with base case settings.

This study suggests that the adaptations to the windows did influence the amount and quality of light available for circadian entrainment, mainly because of the low illuminance values. The results also suggested that low light levels might influence visual comfort. It is evident in all four classrooms that there is a definite potential relationship between the teacher's perception/behavioral responses and optimal visual comfort. The findings from the interviews indicated that the teachers who were pleased with their daylight performance were more likely to be comfortable with their overall lighting conditions and hence have minimal adaptations to their windows.

In contrast, those who were not pleased or comfortable with their overall lighting conditions had numerous adaptations to their windows. The teachers' preferences varied based on the classroom orientation. The preference for having control of window shading and lighting was deemed of great importance. While most teachers preferred daylight to electric lighting, they noted the discontent with the large windows and brightness that negatively impacted their teaching sessions.

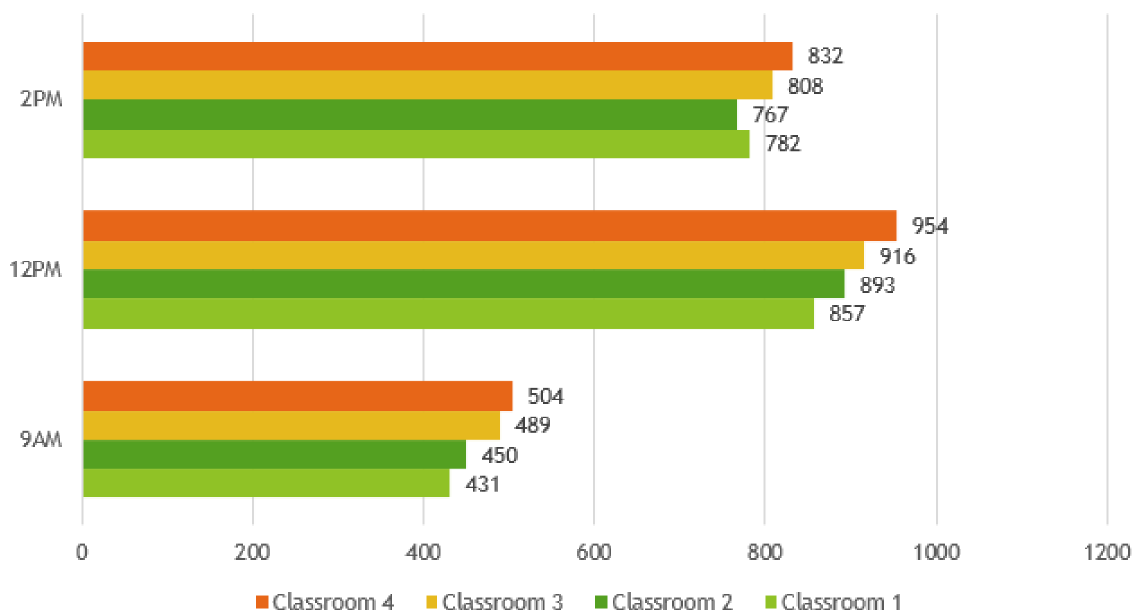


*Figure 42. The base case Average Equivalent Melanopic Illuminance in each classroom during teaching hours at 9 am, 12pm, and 2pm on March 21st***.**

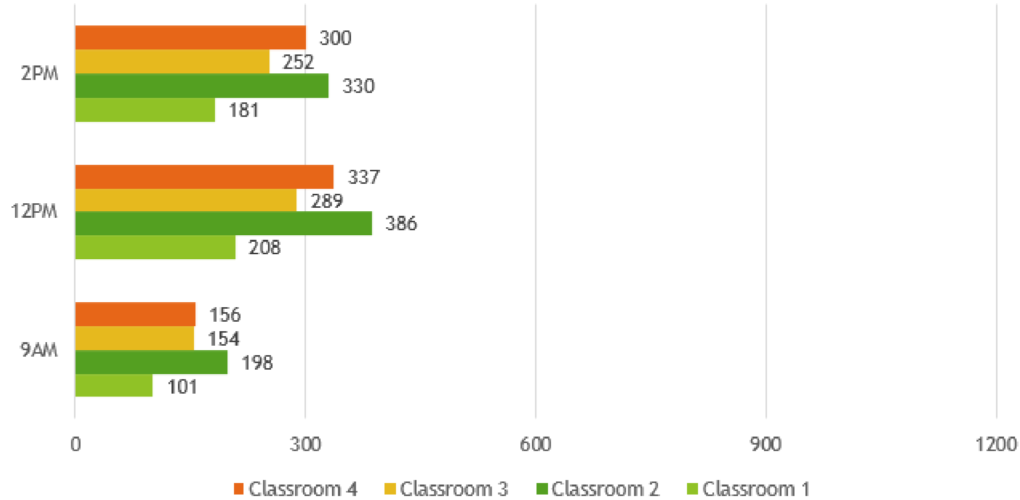


Figure 43. The Average Equivalent Melanopic Illuminance in each classroom with adaptations during teaching hours at 9 am, 12pm, and 2pm on March 21st.

The research findings are a confirmed response to the main research question regarding the teachers' visual comfort needs/experiences. It became apparent in the simulations that there was an identified lighting discrepancies in terms of the melanopic illuminance levels. Figure 42 shows the average base case illuminance levels for all classrooms during teaching hours. According to WELL design standards, the classrooms are well lit with evenly distributed light through out the day except for 9am in some classrooms. While the light intensity values were within the visual comfort recommendation, there were chances of the classrooms being perceived as highly bright when activities requiring low light levels occured. These activities encourage teachers to draw the blinds and attempt to block any light and as a result the melanopic illuminance levels were below recommeded levels (fig. 43).

Chapter 1 reported that the south classrooms tended to have posters on the window apertures while the north classrooms utilized blinds. This observation raised a question about the adaptations to the windows as a response to glare. The other observation was that the north classrooms had the blinds down during teaching hours. While it is evident that north-facing classrooms are not impacted by glare, the chosen preference to keep the blinds down was explored.

4.5.1- South Facing Classrooms

The variables addressed in the interviews suggested that the teachers were unwilling to tolerate glare and high illuminance levels during teaching hours and made preferred responses. The teachers mentioned during the interviews that they experienced significant solar loads during afternoon hours and high daylight penetration into the classrooms in the morning. As shown in figures 44 and 45, the glare simulations performed indicated the sDG values that exceeded visual comfort recommendations and proved that classrooms experienced glare throughout the year. Classroom 1 (fig.44) had 7.3% of views with disturbing glare greater than 5% of the time. Classroom 2 (fig.45) had 4 % of the views with disturbing glare. The areas with close proximity to the window experienced intolerable amounts of glare.

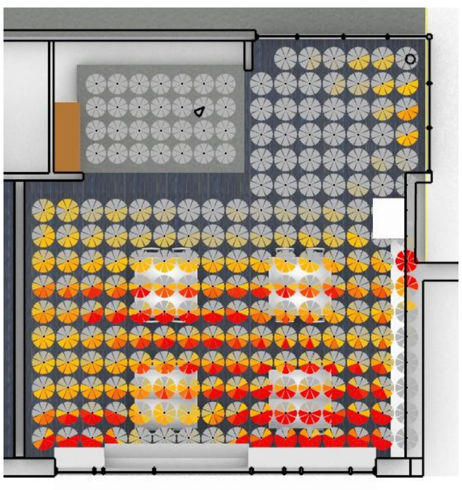


Figure 44. Annual Daylight Glare analysis for classroom 1 during teaching hours.

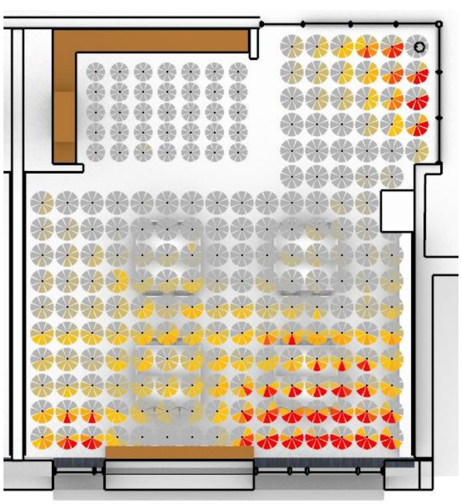


Figure 45. Annual Daylight Glare analysis for classroom 2 during teaching hours.

As a confirmed visual response to discomfort glare, south-facing classrooms 1 made adaptations that could control glare, as shown in the pilot study in sub-chapter 1.7. The simulations revealed that the south-facing classrooms 1 & 2 with adaptations had low light levels that were considered insufficient for circadian entrainment. Furthermore, classroom 1 showed a drastic reduction in menalopic illuminance levels as it had the most adaptations on the window area; thus, considered biologically dark. This evidence confirmed the proposed research question as it is evident that the post-occupancy adaptations in the south-facing classrooms influence visual comfort based on the needs and preferences of the teachers to control glare.

4.5.2- North Facing Classrooms

In this study, north-facing classrooms provided an opportunity to identify issues that conflict with standard daylighting principles. Teachers in north-facing classrooms were generally pleased with their overall daylight conditions but preferred more control over the shading systems. The results indicated that the fabric shade screens in these classrooms moderately affect daylight performance. While the light-colored fabric shade screens reduced the direct sun penetration, the absence of shading on the clerestory made it challenging to control illumination during teaching hours.
As a confirmed visual response to preference and the need to lower illuminance levels, north-facing classrooms 3 and 4 kept the blinds down during teaching hours. The simulations revealed that classrooms 3 & 4 with adaptations had reduced light levels but were still considered sufficient for circadian entrainment. Classroom 3 showed notably low melanopic illuminance levels in the morning but improved throughout the day. Classroom 4 performed well due to the presence of skylights in the second-floor classrooms. However, this did not confirm the proposed research question, as it is evident that the post-occupancy adaptations in the north-facing classrooms did not influence visual comfort based on the needs and preferences of the teachers.

4.5.3- Conclusion

Although the simulation data demonstrated a discrepancy between design light levels and perceived illuminance levels in the North and South-facing classrooms, the open-ended responses to the semi-structured interviews conveyed the importance of perception and control in achieving optimal visual comfort. The results also proved a substantial discrepancy between the design and the preferred post-occupancy illuminance levels in the north and south-facing classrooms based on individual visual perceptions of the teachers. While there are several conclusions to be drawn based on the variation preference based on each individual, it should not lead to solid conclusions about the actual daylight performance in the classrooms. In conclusion, there is a need for further analysis of the interview results for consideration in design applications of future classrooms.

V. CHAPTER V: CONCLUSION

School classrooms are functional and accommodate the needs of both teachers and students. If its users are not satisfied with its performance, a classroom cannot meet its intended functionality. The goal of this post-occupancy evaluation study was to conduct a structured and comprehensive assessment of the overall daylight performance attributes of the classrooms at River Road Elementary school five years after its completion to get feedback about a variety of features, such as the quality of the indoor environment, view satisfaction, and perceived level of illuminance. The results of a post-occupancy evaluation study showed that the classrooms responded to the adaptations made to the windows, which significantly impacted visual comfort. This study used semi-structured interviews to examine how teachers perceived classroom lighting. A simulation and data analysis of the information gathered from the four classrooms was conducted, and some traits were found. Teachers' dissatisfaction can be attributed to the high illuminance and distracting views, which adversely impact their teaching and student participation. However, the teachers still preferred natural light for illumination, concluding that daylight is more effective at providing visual comfort.

5.1- Visual Comfort

This study aimed to evaluate the post-occupancy adaptation of daylight performance for optimal visual comfort. It was important to note that the distribution of daylight and the teacher's perception and behavior in response to daylight plays a significant role in informing this study. Based on building orientation and behavioral preferences, I used glare and circadian lighting assessments to provide recommendations. Visual comfort is one of the critical factors in overall satisfaction with the indoor environment in classrooms. This study investigated the daylight performance of classrooms affected by several factors for optimal visual comfort in the north and south-facing classrooms at River Road Elementary school in Eugene, Oregon. To do so, I created a Rhino model of the elementary school classrooms to identify variables that directly or indirectly impact visual comfort and measure the level of impact by examining several parameters. The findings of this study revealed that all proposed questions are strongly supported, and that visual comfort is influenced by several factors, including light intensity, perceived level of illuminance, view satisfaction, tolerance to illuminance distribution, window orientation, and glare perception in north and south facing classrooms. This study's findings also revealed that all proposed questions in Chapter 1, section 1.2, addressed the identified gaps. The simulations identified significant correlations between the variables, indicating a substantial effect on the optimal visual comfort in these classrooms. In classrooms that experienced discomfort glare (South-facing classrooms), the orientation of the window, light intensity, and teachers' seating position directly affected teachers' satisfaction with the window. The simulations proved that visual comfort is not directly influenced by window size, which according to the teachers' interviews, influenced the students' participation due to the distraction from the outside view.

Based on the parameters considered, the data analysis results, and discussion, the classroom's visual comfort was suitable in the second-floor North and South classrooms. It is evident that while base case levels indicated a suitable illuminance distribution for the classrooms, the adaptations made to control the perceived light levels became a critical area of concern as they had a potential effect on circadian entrainment. According to the data analysis, there is a significant discrepancy in design and preferred post-occupancy illuminance levels in the north and south-facing classrooms. On the other hand, view satisfaction is least important to teachers' visual comfort in their classrooms. Their preference to reduce window apertures, as stated in several interviews, showed that there is a need to adopt measures to improve their environmental quality, especially by controlling illuminance levels during teaching hours for optimal visual comfort.

5.2- Perception & Circadian Entrainment

The findings from the post-occupancy evaluation revealed that the adaptations could potentially impact circadian entrainment in both the North & South-facing classrooms. The results were evaluated based on the amount of melanopic and photopic lux in each classroom. In the north classrooms, the average melanopic lux was higher than in the south classrooms during the spring months with the different adaptations applied to the windows compared to the base case scenario where the south-facing classrooms had a higher average melanopic lux.

With the adaptations to the windows, the south-facing classrooms required more illuminance than the north classrooms and were considered biologically dark. Based on the data analysis, the classrooms require sufficient melanopic illuminance to obtain optimal visual comfort. Daylight is known as an ideal source of melanopic illuminance; hence the need to address the post-occupancy adaptations is crucial. This study showed that while the south-facing classrooms are more susceptible to severe daylight conditions than the north-facing classrooms during spring, they were both impacted by the teacher adaptations to the windows. This response led to the conclusion that regardless of the building orientation, the visual responses were highly based on perception and visual preference. This paper made critical observations on the implications of window aperture adaptations on circadian entrainment. Classroom 1, for instance, was proven to be biologically dark with the adaptations. Adaptations added as a response to glare were detrimental to the daylight performance of the classroom. As a result, the teachers were at risk of not receiving the adequate amount of illuminance required for circadian entrainment. As shown in the discussion, the adaptations on the south-facing classrooms may have been considered adequate for glare control, but only in the proper context. It also had adverse effects on the overall daylight performance and quality. Overall, the results of this study align with previous literature, which indicates there is a relationship between human perception and circadian entrainment.

5.3- Limitations and Future Research

It is important to note several limitations to this exploratory study. First, the major limitation was the small sample size of teachers participating in the semi-structured interviews. Perhaps a greater number would have allowed detecting a significant trend regarding the impact of daylight performance on visual comfort in the classrooms. Second, although the research framework illustrated in Chapter 1 laid out most aspects of a post-occupancy evaluation regarding daylight performance, this research was limited by studying classrooms in one elementary school. Third, the study would have had a more significant impact if it were a comparison of newly built schools in Climate zone 4 C. While this study aimed to understand teachers' perceptions, it is evident that further research is required in this area. The bottom line is that occupants will never be satisfied by any daylight-driven design unless they perceive a significant benefit. In addition, when assessing teachers' variables, there was no consideration of whether they were aware of or familiar with the constructive strategies that allow adequate daylight management focusing on adaptive behaviors and the effects on circadian entrainment. Therefore, their assessment could have contributed to further explaining the adaptations' reasons.

Moreover, other variables that are not related to daylight but could be a potential cause or reason for the adaptations had been excluded from this study and could have a substantial weight in predicting future studies. Another limitation was that the study was a post-occupancy evaluation requiring field studies and human subjects for the study's validity. Finally, due to the study occurring during a school year, on-site studies were limited to after-class hours, which made it challenging to collect data for the times of day that were being addressed in this research.

The following summary of limitations emerged from this exploratory study:

- The daylight metrics considered in the study showed a potential relationship with the teacher's perception/behavior; this was not explored in depth since the study was limited to one season. (spring)
- ALFA simulates circadian metric EML, which accounts for the vertical illuminance at eye level and the spectral distribution of daylight (entering through windows and reflected by surfaces). The limited material library made it challenging to simulate realistic material surfaces and their spectral qualities.
- The WELL standard bases its design on a single viewpoint/ direction within a classroom setting. This standard limit the option to examine several points of view within a space and provide an average recommended EML based on the number of viewpoints selected within a classroom. The elementary school classroom setting does not emphasize a single point of view due to the dynamic nature of the classroom.
- It was challenging to establish a definitive relationship between visual comfort and teachers' subjective perceptions: the individual preferences of the teachers varied based on the perception of daylight within their classrooms. The responses from the semi-structured interviews were analyzed collectively regardless of the classrooms' daylight performance. This analysis is a potential limitation as some spaces non-compliant with minimum WELL standard requirements were positively perceived and accepted by teachers.
- Several parameters impact a teacher's comfort, circadian rhythm, and perception of daylight in a classroom setting. These parameters may include the design and non-architectural features of the classroom. There are numerous issues to be resolved regarding safety & security and physical distractions during teaching hours that could impact the daylight performance in classrooms.

As a result of this study, it is essential to note that classrooms should be designed to be used efficiently and comfortably to recognize the occupant's goals and needs in their entirety. Furthermore, it is evident that to promote a positive perception of daylight and daylight response behavior, providing a comprehensive education guide and curriculum facilitates the use and adaptation to effective daylight practices by integrating them into the learning and teaching process. To ensure the full potential of the classrooms and window apertures, designers can communicate with the teaching staff about their expectations and design intent by creating opportunities for continuous education. In the meantime, research must continue to identify potential loopholes and allow function and perception to be a continued review topic against the set design expectation.

APPENDIX A

Definitions

1. Useful Daylight Illuminance (UDI)

Useful Daylight Illuminance (UDI) refers to the percentage of time a target range of luminance at a point in space is met by daylight. A lower and an upper illuminance limit values are proposed to split the analyzed period into three categories:

- The upper range represents the percentage of the time when an oversupply of daylight might lead to visual discomfort.
- The lower content represents the percentage of the time when there is too little daylight.
- The intermediate range represents the percentage of the time with the illuminance level.

Useful Daylight Illuminance UDI has ranges of 100 to 2000 Lux (UDI 100-2000) and over 2000 Lux (UDI 2000). This index indicates the percentage of daylight hours for most activities during most of the year. The second indicates the rate of daylight hours exceeding 2000lux, indicating visual discomfort and glare problems. Research has shown that the UDI method is more accurate and valuable than the daylight factor and autonomy calculations.

2. Spatial Daylight Autonomy (sDA)

Spatial Daylight Autonomy (sDA) refers to "the sufficient ambient daylight level at certain points during the year." It refers to the amount of an analysis area that meets a minimum daylight illumination requirement during a specified period." First, the calculation involves assessing Daylight Autonomy in each spatial grid point over the area of interest. Then only those points with DA not smaller than a given reference value are included in the summation, increasing the value of sDA. To elaborate, sDA (Spatial Daylight Autonomy) describes the percentage of floor area that receives at least 300 lux for at least 50% of the annual occupied hours on the horizontal work plane (30" above the floor or work plane height).

3. Annual Sunlight Exposure (ASE)

Annual Sunlight Exposure (ASE) refers to the percentage of space that receives too much direct sunlight (1000 Lux or more for at least 250 occupied hours per year), which can cause glare or increased cooling loads. Precisely, ASE measures the percentage of floor area that receives at least 1000 lux for at least 250 occupied hours per year.

4. Discomfort Glare Probability (DGP)

Discomfort Glare Probability (DGP) involves evaluating the level of illuminance perceived by the observer using the term vertical illuminance (Ev). For this reason, DGP shows a stronger correlation with the user's response regarding glare perception. Thus, according to Suk et al., it would be the most appropriate metric to analyze absolute glare issues.

5. Visual Discomfort and Glare

Visual discomfort from glare has been known as the main factor for eye strain. Glare can occur due to an unsuitable range or distribution of luminance, higher than the adapted visual system's visual system, or extreme luminance contrasts. In terms of glare's impact on visual function and comfort, it can be defined as two main types of vision: either disability glare, in which there is a reduction in the ability to see details or even objects, or discomfort glare. This irritating or distracting effect does not necessarily impair the vision. Identifying disability glare is less challenging due to its objective character, which has its own set of predictive models not outlined in this paper. On the contrary, under discomfort glare conditions, the observer experiences unexpectedly early fatigue, feelings of discomfort, or headaches which are long-term effects of being exposed to that lighting condition and are the primary concern in lighting design.

6. Equivalent Melanopic Lux (EML)

EML is an index used to measure the biological effects of light on humans and suggests relative circadian efficacies for various light sources. EML is a value obtained by quantifying the effect of light on the human circadian cycle and is calculated by multiplying the photopic illuminance (in lux) by the melanopic ratio according to the type of light source, as shown in Equation (1).

EML=Visual lux X Melanopic ratio, where *visual lux* refers to the photopic illuminance that the human eye can perceive, and *melanopic ratio* is a conversion constant necessary to convert photopic illuminance to melanopic illuminance.

Interview Questions

Section A- Classroom Design:

1. Please tell me how the design of this classroom enhances your teaching experience.
2. Please tell me how the design of this classroom hinders your teaching experience.
3. How would you describe any issues that might impact student participation in your classroom?

Section B: Daylighting systems:

4. Please describe your experience with daylighting in your classroom.
5. Do you think the amount and locations of windows and skylights are sufficient to for the proper functioning of the classroom? If not, what other elements should be considered?
6. Do you have sufficient pin-up space in your classrooms?
7. Do you have sufficient storage space in your classroom?
8. Do you think you have enough control over personal space, adjustability of furniture, lighting, and flexibility of your classroom? How important is this to you? Please explain.

Section C: Adaptations/Perception

9. During teaching hours, how often do you draw down the window shades? Do you open them back? When?
10. During regular teaching hours, how often do you turn on/off the electric lights? Why?

11. I noticed you are pinning-up student work and posters on the windows. Is this because of the lack of sufficient wall space?
12. Would you like to suggest additional elements that should be included in improving the classroom design for you?
13. If given the means or opportunity, what would you do to change the daylight and electric lighting system in your classroom?
14. Do you have any additional comments or anecdotes about your classroom design you would like to share with me?

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