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Workstation partitions are used in open plan offices for many reasons and come in a wide variety of materials, types, and shapes. The position, height, and orientation of partitions affect the amount and distribution of daylight entering a building as well as all forms of thermal transfer through windows. However, these potential impacts cannot be determined if not adequately addressed in guidelines and standards, and could mislead decision-making during design stages and hamper the refinement of office furniture manufacturing.

This study outlines the daylight performance of workstation partition alternatives in a large open plan office on the 11th floor of a high-rise building located in downtown Raleigh, NC. For this purpose, 60 alternate combinations of workstation partitions including partition materials, layouts, heights, and orientations in four daylight zones (north, south, east, and west) were conducted using Radiance engine V.4.2.0. These combinations were analyzed based on two recently recommended annual climate-based daylighting metrics and performance criteria proposed by Illuminating Engineering Society (IES) 2012, spatial Daylight Autonomy (sDA) and Annual Sunlight Exposure (ASE), to evaluate the feasibility and potential effectiveness of workstation partition design.

Findings indicate that partition material, height, orientation, and layout have robust impacts on daylight sufficiency and the risk of daylight excessiveness. Annual daylighting simulation results report that sDA values in this study space range between 46.6% and 84%, and ASE differs by 10.6% to 15.2%. It is also revealed that the highest annual daylight sufficiency values and the lowest daylight excessiveness belong to those partitions oriented perpendicular to windows based on spine layout.

Exploring these alternatives in detail helps draw attention to the possible partition layouts that are both effective and economical to overcome glare and visually uncomfortable conditions in open plan offices. More widespread application of daylight-based partition design in open plan offices could result in a better understanding of their performances, as well as improvements in their overall efficiency. These improvements could provide a comfortable, productive and healthy environment for occupants as well as savings in annual energy consumption.

A COMPARATIVE STUDY OF WORKSTATION PARTITIONS IN AN EXISTING SIDE-LIT OPEN PLAN OFFICE WITH DAYLIGHT RESULTS USING ANNUAL CLIMATE-BASED SIMULATIONS

by

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Approved by

____
Committee Chair

Dedicated to my beloved parents Mehri and Mohammad,

who have been my source of encouragement and inspiration throughout my life,

and my amazing husband, Amir,

who is my best friend and the love of my life.

APPROVAL PAGE

This thesis written by Malak Modaresnezhad has been approved by the following committee of the Faculty of The Graduate School at The University of North Carolina at Greensboro.

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CHAPTER I

INTRODUCTION

This comfortable inside buildings is not limited to the aesthetic of the space. There are design strategies and environmental factors that could also impact occupants' comfort positively. Accordingly, it is well accepted that indoor environmental quality in buildings has a substantial role on human comfort, productivity, health, and well-being (Teague, 2010; Lee & Guerin, 2009; Menzies & Wherrett, 2005; Marquardt, 2002). People in industrialized societies spend around 90% of their time indoors (Leech et al., 2002; Schweizer et al., 2007; Jenkins et al., 1992). We typically spend half of our life at work, and a well-designed workplace with a high-quality indoor environment could relieve potential discomfort and help employees' alertness and productivity (Veitch, 2011).

According to the American Society of Interior Designers (ASID, 1999) one of the top three factors which affect performance and job satisfaction is the design of the physical workplace. According to McGuire & McLaren, (2009) progresses in the physical design of the workplace may increase employee productivity by 5-10%. Conversely, chaotic workplaces and physical environments could result in negative effects on employees' efficiency (Carnevale, 1992).

Lee & Guerin (2009) investigated the quality of indoor environments in three categories: office layout, furnishing, and lighting quality. According to the broad range of studies (Lee & Guerin, 2009; Kim & Dear, 2013), office layouts impact employees' productivity and organizational performance by providing satisfaction with the level of visual privacy, satisfaction with easy interaction with co-workers, and satisfaction with the available space for individual and sufficient storage. Office furnishing quality also shows strong positive effects on occupants' satisfaction and performances through personal office furnishing, adjustability of furniture, colors and textures of flooring, and surface finishes (Lee & Guerin, 2010).

In addition, lighting has a significant direct impact on all aspects of human life: "Light is the most important environmental input, after food and water, in controlling bodily functions" (Wurtman, 1975, p. 69). Both daylight and artificial light have identical effects on visual tasks, performance, and overall worker satisfaction, (New Buildings Institute, 2012; Leslie, 2003) although daylight has benefits over artificial light sources in preserving circadian rhythmicity and overall well-being (Edwards et al., 2002). "Daylighting can provide a continuous spectrum of visible light and the high levels of illumination beneficial for maintaining healthy cycles of wake and sleep" (New Buildings Institute, 2012, Para 3; Leslie, 2003). In other words, natural changes in intensity and color temperature of daylight regulate the circadian cycle, helping us to be more active during the day and sleep better during the night (Figueiro et al., 2006; Joseph, 2006).

Several daylighting studies verify the importance of occupant satisfaction in spaces due to view quality and dynamic interior (Veitch et al., 2007; Heschong & Van Den Wymelenberg, 2012; Borisuit et al., 2015). Daylit office environments increase employees' comfort, productivity, satisfaction, health, and well-being (Mardaljevic et al., 2009; Lee & Guerin, 2009). Daylit spaces can fulfill occupants' visual needs, provide more pleasant and attractive indoor environments, and alleviate thermal issues by decreasing the use of energy for lighting, warming, and cooling (Reinhart & Wienold, 2011; Alzoubi et al., 2010). However, overlit spaces can cause glare and visual discomfort, especially with sunlight penetration when the amount of daylight is not sufficiently controlled.

There are multiple work styles and preferences for different types of workspaces. The most well-known type of workspace is an open plan office with moveable partitions (above 70%). The California Energy Commission et al. (2012) explained the importance of investigating natural light in open plan offices for two main reasons: "Firstly, open office spaces provide a larger population of occupants for the study, and secondly, because they present a more necessary concern for daylighting visual quality and energy balance" (p. 27).

The workstation partition substantially impact on daylight performance (New Buildings Institute, 2015). According to the New Buildings Institute (2015), the height, orientations, and materiality of partitions (reflective surfaces of partitions) affect the amount of transferred daylight from windows and the lighting conditions of a space.

However, daylit buildings are rarely studied in use or examined in terms of the impact of interior design strategies on the level of daylight availability. Further studies are required to diagnose the specific daylighting design strategies in order to improve the current design patterns guide.

This study is conducted in order to compare 60 alternate workstation partition designs in four daylight zones (north, south, east, and west) via annual climate-based daylighting simulation, spatial Daylight Autonomy (sDA) and Annual Sunlight Exposure (ASE), in a large open plan office on the 11th floor of a high-rise building (with an area of approximately 27,770 ft^2), located in downtown Raleigh, NC. Two different annual climate-based daylighting metrics, sDA and ASE, allow a daylit space to be evaluated over the course of the year and provide significant direction for designers regarding the sufficiency of daylight illuminance available in a design. The main objective of this comparison study is to determine which workstation partition maximizes diffuse daylight sufficiency and minimizes daylight excessiveness in each direction of open plan office spaces. These factors have led to a range of design strategies to balance daylight transmission, improve the performance of future daylit buildings, and refine daylighting design criteria.

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CHAPTER II

LITERATURE REVIEW

This chapter includes studies about three main areas of inquiry: (1) open offices, (2) lighting and daylighting quality and (3) codes and standards. This section is followed by a summary of knowledge gaps and suggested next steps for further analysis.

Open Offices

People in industrialized societies are typically awake for over two-thirds of the hours during a day (16.5 hours) and they spend almost half of their lives at work within indoor physical environments (Leech et al., 2002; Schweizer et al., 2007; Jenkins et al., 1992) that could have substantial impacts on their feelings, productivity, health, and well-being (Teague, 2010).

There are multiple work styles and preferences for different types of workspaces. The most well-known type of workspace is an open plan office with moveable partitions (above 70%) (Brill et al., 2001). The open office was initially proposed by a German organization in the 1950s in order to simplify communication and idea flow by implementing regular furniture and large potted plants in organic geometry (Marquardt, 2002). However, a lack of privacy was the main reason for dissatisfaction with open plan office layouts, which led to the design of cubicles to restore privacy (De Croon et al., 2005; Danielsson & Bodin, 2009; Hedge, 1982). An American furniture company developed larger surfaces, multiple desk heights, and modular components to save space in 1964 (Musser, 2009). In the late twentieth century, the progress caused by mobile technology led to major changes in open plan offices that mixed cubicles, open workstations, private offices, and group workstations (Gillen, 2006).

The best-designed offices will lead to the most productive and dynamic working relationships and will also save money. More companies are redesigning offices to combine open plan layouts in an effort to encourage collaboration and save money by doing away with traditional set-ups and private offices. Nevertheless, many employees complain about the lack of privacy in an open office, which causes concentration problems. Below are mentioned some of the many pros and cons of open plans:

Table 1. Pros and Cons of Open Plans

pros	**Staff Advantages**	A lack of walls and physical barriers: 1. Make it easier for the employees to interact with each other. 2. Enhance information flow and teamwork. 3. Share advice or assistance without having to schedule a formal meeting. 4. Interactions are more frequent and informal.
	Business Advantages	1. Increase collaboration to lead to business innovation and advancement. 2. Reduce costs tied to construction, utilities, office equipment, time and materials required to create office space. 3. Reduce heating, cooling, and electricity expenses. 4. Save on equipment investment by sharing use of resources such as printers, copiers and staplers. 5. Provide greater flexibility to accommodate evolving employee needs. 6. Accommodate greater numbers of employees in reduced amounts of space.
Cons	**Staff Disadvantages**	1. Difficult for employees to focus on their work since the high level of interaction leads to noise and distractions. 2. Lack of privacy: computer screens are easily visible and telephone conversations are likely to be overheard. 3. Facilitate the spread of disease that can affect the health of the entire staff.
	Business Disadvantages	1. Distractions impact productivity and are detrimental to the business as a whole. 2. Business production may be reduced by the higher rate of absenteeism (because disease spreads more easily). 3. Lack of privacy may give rise to legal or ethical issues. 4. Lighting, heating, and air conditioning to suit all employees' tastes can be difficult to achieve.

The concept of the open plan office keeps developing due to its benefits in simplifying communication and minimizing costs. Hence, understanding how to evolve the indoor environmental quality of open offices helps provide productive and pleasurable work areas for employers.

The impact of indoor environmental quality on building occupants' satisfaction is considered by five studies (Astolfi & Pellerey, 2008, Wong et al., 2008). The parameters that contribute to building occupants' satisfaction are air quality, thermal, visual, and acoustic environments. Besides, there are other factors that can influence occupants' satisfaction including satisfaction with the view, control over the indoor environment, privacy, as well as workstation furniture layout and partition design. Hence, recent studies revealed that the most important component of environmental satisfaction in open plan offices is furniture layout and partition design (Marans & Yan, 1989; Veitch et al., 2007; Frontczak et al., 2012).

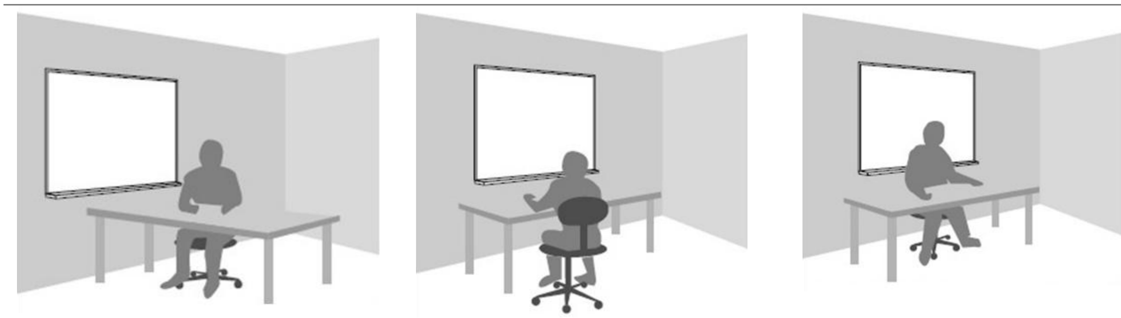
Physical layouts of a workplace play a significant role in influencing the behavior of employees and maximizing their productivity (Allen, 1997). According to McGuire & McLaren (2009), employees' productivity increases 5-10% when the physical design of the open offices improves. The level of employee productivity increases through facilitating interaction and privacy, formality and informality, and functionality and interdisciplinary collaboration, which consequently leads to employees' well-being (Robertson et al., 2016) and better business results (Mohr, 1996).

Workstation partitions are one of the most effective interior features that can be considered in the design of office layouts. They play an important role in making a functional and productive working environment. O'Neill (1994) considered the impact of partition type and partition height on environmental satisfaction. Acceptable lighting and ventilation, along with satisfaction concerning privacy and acoustics, contribute to an overall comfortable work environment. Previous studies demonstrated that the shape of the partition as well as the height and degree of enclosure correlate with perceptions of visual privacy (Carayon & O'Neill, 1993) and the fulfilment of daylight needs (Sundstrom et al., 1982).

Partition heights and workstation sizes are entirely subject-based. It depends on workers' behavior, job requirements, lifestyles, and expectations. Some employees prefer to have daylight over privacy; therefore, partitions have to be low enough to bring natural light into the space (Judge et al, 2001). However, others may prefer privacy rather than daylight, which could result in higher partitions to provide better privacy and acoustics. Overall, a balanced interaction between these factors should be considered.

Inside lit spaces, which have been a primary way of introducing daylight into buildings and serve to facilitate views and ventilation, office partitions must be kept low (42" or less) and unobtrusive to increase the amount of diffuse daylight, parallel to the direction of the daylight distribution to ensure the maintenance of views to the outside. On the contrary, higher partitions (48" or greater) should be used perpendicular to the perimeter glazing to provide privacy, a sense of enclosure, and not block the direction of the daylight (New Buildings Institute, 2015). Reinhart (2002) studied that high partitions (60"or greater) in an office decrease the level of light by 20%, compared with 48" partitions.

Moreover, changing the material of partitions from opaque to transparent or translucent enables the light to penetrate further into the space and increases the amount of diffuse daylight when high partitions are required. Additionally, it is critical that the partition finishes be light reflective, especially where they occur above 42” (New Buildings Institute, 2015).



The Window to the Side of the Desk	Facing the Bright Window	Back to the Window
- Task is well illuminated - The source is not in direct line of sight - The most comfortable sitting position	- Creates a harsh contrast in comparison to her or his relatively dark task - Extremely tiring for the eye to have both the window and task in view	- Task may be shaded and too dark to see easily - Computer screen may be difficult to see if it reflects light

Figure 1. Direction of Windows and Furniture By Schumann et al., (2013).
Image Credit- (Schumann et al., 2013)

Studies show that interior surface finishes significantly impact brightness perception within interior space. Surface reflection and the color of ceilings and walls influence daylight availability, electric lighting requirements, and individual comfort. Thus, the effective selection of finishes can substantially improve daylighting performance. Dark surfaces reflect less light than bright surfaces and create an unsatisfactory luminous environment with little indirect or reflected light. Meek & Van Den Wymelenberg (2014) suggest that in side-lit buildings the wall at the opposite side of the windows “receives sufficient daylight and has a relatively high reflectance value (>70%), so that it can balance the brightness of the view through the perimeter windows” (p.34) and distribute a uniformity of illumination into the interior space.

According to the New Buildings Institute (2012), designing office ceilings and surfaces surrounding windows with a minimum of 80%- 90% reflectance is preferred. Work surfaces, vertical partitions, and walls higher than 30” should have a light color with 65%-70% reflectance (walls 50%-70%, if wall contains windows), floors with not less than 20%- 40% reflectance, and furniture 25%-45%.

Lighting and Daylighting Quality

In commercial buildings, lighting is the major category of energy consumption, which also represents the largest electricity use (35%) (DiLaura et al., 2011); surprisingly, the majority of lighting consumption is during daylight hours. With proper electric lighting control, daylighting can diminish electric lighting use by 30% to 60% in the daylit region (DiLaura et al., 2011). Using daylight correctly could reduce energy consumption and enhance Indoor Environmental Quality in commercial office buildings.

Successful daylighting design is considered throughout the building design process, from site planning to architectural, interior furniture layout, and lighting design.

Daylight in buildings includes direct sunlight, diffuse skylight, and light reflected from the elements surrounding them. Figure 2 illustrates the components of daylight. Sunlight is the direct light from the sun and daylight, or the light of day, is the combination of all direct and indirect sunlight during the daytime. Sunlight is too bright and hot, which leads to visual and thermal discomfort; on the other hand, daylight is much more gentle (Pande et al., 2011). Daylight provides efficient and gentle illumination without the undesirable effects of direct sunlight throughout a space and makes available the best visual quality and the most energy savings. Acceptable daylighting design relies on two major strategies: maximizing the use of diffuse daylight and minimizing the penetration of direct beam sunlight. Direct beam sunlight, a bright source of light (up to 100,000 lux), negatively influences occupants' visual comfort (Jones et al., 2004).

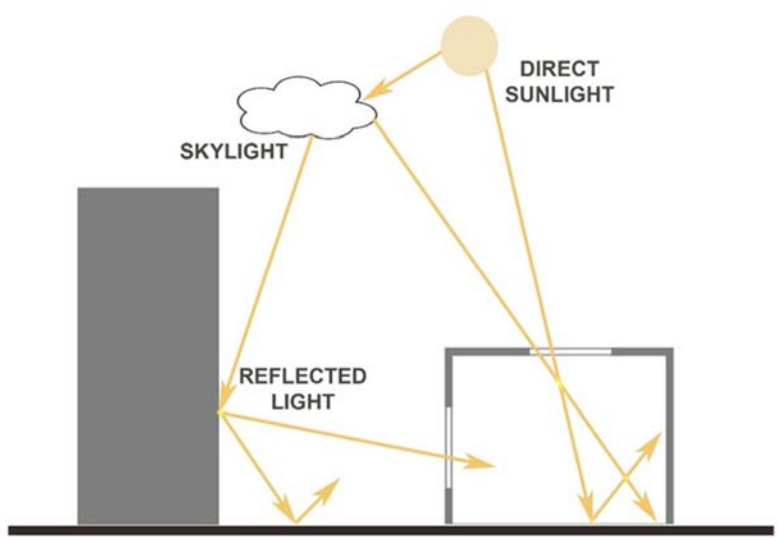


Figure 2. The Components of Daylight.
Image Credit- Author

Daylight could be extended into a space through several architectural elements such as windows, skylights, roof monitors, and clerestories; and each of these elements creates a daylighting zone. There are three daylighting zones: primary side-lighting, secondary side-lighting, and top-lighting zones. Primary and secondary side-lighting zones are illuminated by windows, while top-lighting zones are illuminated by skylights, roof monitors, and clerestories (Schumann et al., 2013). According to Schumann et al. (2013), a side-lighting strategy (vertical windows) provides natural light and views, which includes the distance from the floor to the head of a window to determine how far sufficient and beneficial daylight comes into the space. The primary sidelit daylight zone is a daylit area directly adjacent to one or more windows and it is one window head height deep into the area. The secondary sidelit daylight zone is an area not directly adjacent to a window that still receives some daylight and is calculated by two window head heights deep into the area (Schumann et al., 2013). Figure 3 shows primary and secondary sidelit daylight.

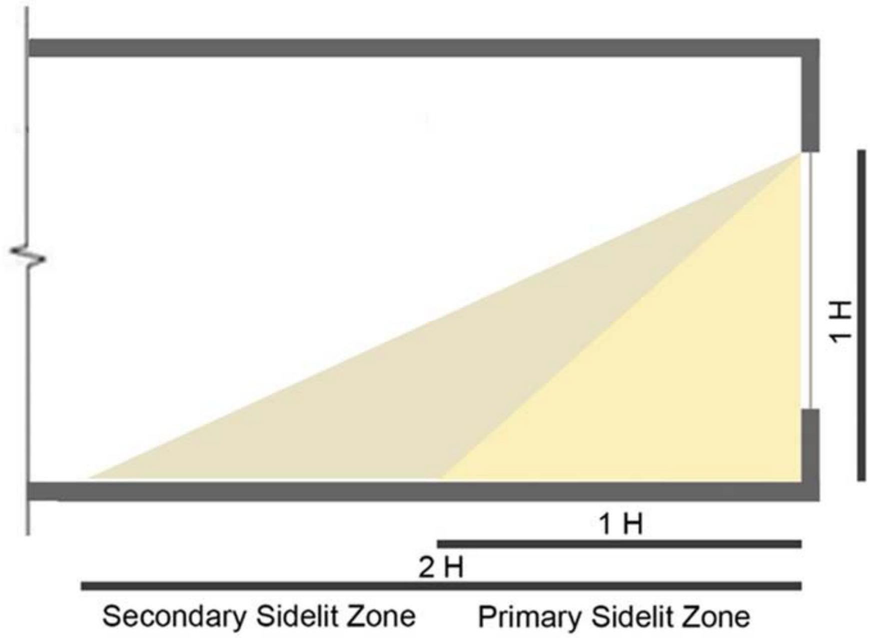


Figure 3. The Primary and the Secondary Sidelit Daylight Zone.
Image Credit- Author

Major Factors Impacting the Amount of Daylight

Studies showed that the amount of daylight in buildings generally depends on four major items: 1) Climate, 2) Latitude, 3) Obstructions and reflections on site, and 4) Building design.

1) Climate: Climate plays significant roles in daylighting design in terms of sky condition, daylight sufficiency, sun position, visual comfort, thermal issues, and energy performance. Hence, the first step in daylighting design includes identification of seasonal climate conditions, especially sunlight probability and quality of regional patterns of cloud cover (Johnsen & Burnett, 2010).

2) Latitude: The latitude of buildings' locations affects the length of daylight and solar availability in different seasons of the year. The latitude of the site illustrates the maximum and minimum solar elevation by moving away from the equator towards the north or south. According to the season and latitudinal position, the length of day and night does vary. When the latitudes increase, the difference in the length of the day between summer and winter becomes longer. For the northern hemisphere, the sun is at its highest level (the highest peak of global illuminance) during the summer and is approximately two and a half times greater than the lowest level during the winter (Johnsen & Burnett, 2010). Figure 4 shows the angle of sun in summer and winter.

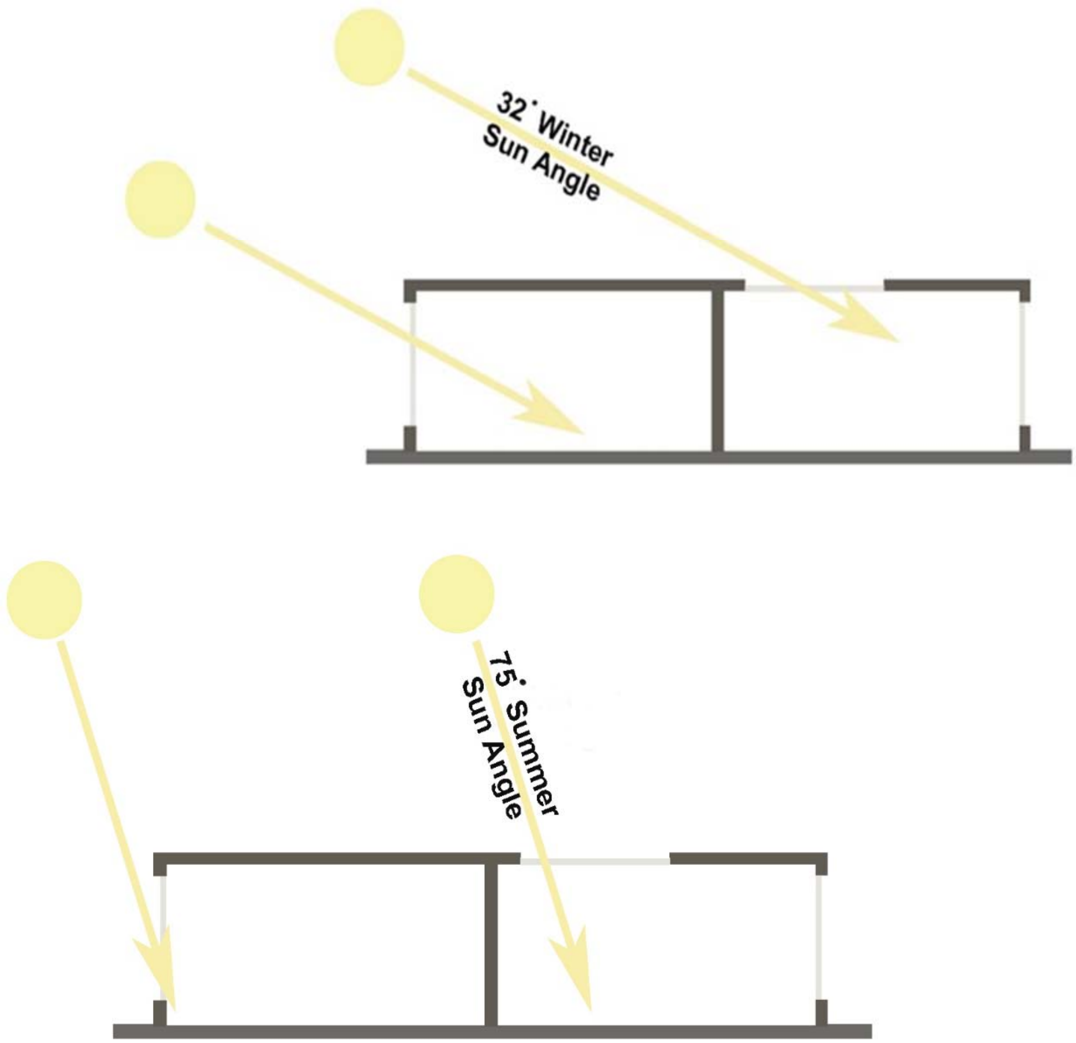


Figure 4. Angle of Sun in Winter and Summer.
Image Credit- Author

3) Obstructions and reflections on site: Daylight typically enters into a space through direct sun exposure or reflections from the exterior obstruction. Investigating the obstructions at a building site helps architects to design buildings to bring maximum daylight with respect to daylight availability and minimize reflection from surrounding buildings (Johnsen & Burnett, 2010).

4) Building design: A building's geometry significantly impacts daylight availability within the space. Building orientation is one of the major parameters that provides adequate daylight in the space. In the northern hemisphere, light coming from the north is mainly diffused and provides a pleasurable and visually comfortable light throughout the day (Day, 2011). There is direct solar radiation on the south façade of the building. Southern glazing provides an excellent source of natural daylight and is also a good source of solar heat gain in the winter months. Since controlling the sunlight on the south side of the building is easy, having the opening to the sun in this side is often best (U.S. Green Building Council, 2015). According to Day (2011), the east and west façades "have a variety of conditions resulting from a combination of both sun and skydome light" (p.8). The least desirable sources of daylighting are east- and west-facing windows since these two sides experience low angle sunlight. During summer, east-facing windows can be a major source of heat gain in the morning and west-facing windows can be a major source of heat gain in the afternoon (Schumann et al., 2013).

Table 2. Description of Façade Orientation

The northern façade	Receives diffuse daylight with minimal solar heat gains Unlikely to get direct sunlight during the day Has the lowest energy savings due to the absence of direct sunlight Always has a higher energy consumption than other orientations In the Northern Hemisphere, shading would only be needed in the early morning or late afternoon Not enough heat gain during winter
The southern façade	A good source of solar heat gain in the winter months High level of light intensity during the day and the year Careful consideration of the appropriate shading devices is needed to save energy and provide occupants comfort
The western façade	Excessive daylight should be controlled due to solar heat gain and intense glare issues, especially because of the lower altitude of sun throughout the year in the late afternoon and evening Shading is critical to provide comfort and avoid solar heat gain Difficult to shade but various steps can be taken: Vertical fins and interior shades can be used to block direct afternoon sun The use of landscaping to shade west exposures is the best option to consider
The eastern façade	Shading is critical to provide comfort and avoid solar heat gain Vertical fins and interior shades can be used to block direct afternoon sun

Windows play crucial roles in bringing daylight into the space, connecting the interior spaces to the outdoors, and maintaining views. Farley & Veitch (2001) detailed the importance of windows on workers' productivity and well-being. Windows provide useful daylight depending on the orientation; however, each window orientation must be treated differently to get the best results (Farley & Veitch, 2001).

Studies indicated that window to wall ratio (WWR), visible transmittance (VT), and distance of the workstation from windows are variables which significantly impact energy performance, heating, cooling, and lighting end uses as well as access to natural environment, daylight, ventilation, and views. WWR is the percentage of window (glazing) area to wall area. VT is the amount of visible light that is transmitted through a window. Visible transmittance is influenced by the glazing type, the number of panes, and any glass coverings. The combination of WWR and VT is an Effective Aperture (EA) which is the amount of light that effectively illuminates the space (VT*WWR=EA) (Schumann et al., 2013; U.S. Green Building Council, 2015). Thus, the average daylight illuminance for large windows with low-transmission glass is similar to small windows with high-transmission glass. Figure 5 shows the different kinds of Visible Light Transmission (VLT).

Figure 5. Different Kinds of VLT (Visible Light Transmission).
("Window Tinting Experts," 2013)

It is well accepted that sitting next to windows may result in thermal and glare discomfort, which leads to decreased work performance. Cai & Marmot (2013) investigated occupants' thermal comfort in different orientations of the building and found that sitting next to the windows on the south façade could cause serious discomfort for occupants in comparison to east, west, and north. The highest satisfaction with overall thermal comfort for every orientation is sitting two desks away from windows. For the south, the satisfaction rating is up to three desks; for the east and west, the desks are farther from the windows and occupants are satisfied no further than two desks from windows because in the morning and afternoon, the sun raises the temperature near the windows (Cai & Marmot, 2013).

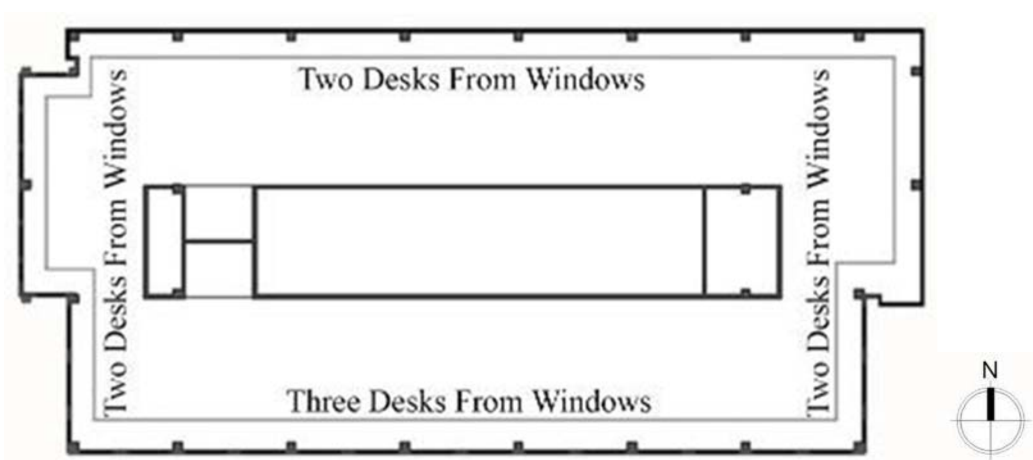


Figure 6. Distance of Desks from Windows

Codes and Standards: Daylight Measurement

The term metric implies a useful, complex assembly of information and a mathematical combination of measurements and characteristics; nevertheless, a metric may not be directly measurable in the field. It is essential for designers to investigate daylight metrics, design spaces with good daylighting, and optimize design for the most energy efficiency.

In the 1940s and 1950s, the British Building Research Establishment (BRE) used manual calculation tools such as nomographs and “pepper pot” (p. 9) diagrams to estimate the ratio of daylight illumination available outside and compare it to the inside of a space (California Energy Commission et al., 2012). In the 1980s, basic computer analysis tools were developed to evaluate daylighting. Many codes and standards which are still used today to specify daylight performance, such as the daylight factor or window head heights, go back to the 1980s BRE evaluations and have increased the use of daylight (California Energy Commission et al., 2012). The following citation, seen below, represents metrics for measuring daylighting in built environments during the last decade:

> Static daylight metrics measured at a single point in time such as Daylight Factor (Moon & Spencer 1942 and Waldram 1909) and LEED 2009 9AM/ LEED 2009 3PM, have recently fallen out of favor and instead annual dynamic daylighting metrics such as Daylight Autonomy (Reinhart et al. 2006), Useful Daylight Illuminance (Mardaljevic and Nabil, 2005), continuous Daylight Autonomy (Rogers, 2006), Daylight Saturation Percentage (Collaborative for High Performance Schools, 2006) were promoted in order to better incorporate project design parameters, climate, and the annual variability of daylight. (Nezamdoost, 2015, p. 56)

These days, computer software is used to simulate daylight, which has the ability to render spaces for point in time analysis and run annual simulations. Point in time measures minimum and glare-causing light levels at one point in time for a singular design condition. On the other hand, point in time does not demonstrate if a building is performing well or not, but it is useful to know for best or worst case situations. New daylighting metrics have been proposed to measure dynamic climate-based conditions. Dynamic daylighting metrics, which are location-based, predict annual daylighting conditions over the entire year and help architects make good design decisions. These metrics require substantial computational power to process a large number of variables such as climate data, site data, sun control device operation, and occupancy schedules (Illuminating Engineering Society of North America & Daylight Metrics Committee, 2012).

Lighting Measurement #83 (LM-83)

In 2012, the Illuminating Engineering Society (IES) published the calculation guide Lighting Measurement #83 (LM-83), explaining "IES LM-83-2012 was created to develop a new suite of metrics capable of describing multiple important dimensions of daylighting performance in an existing building and a new design, from concept through construction documents" (Illuminating Engineering Society of North America & Daylight Metrics Committee, 2012, p. 1). IES LM-83 describes two different annual climate-based daylighting metrics and performance criteria, spatial Daylight Autonomy (sDA) and

Annual Sunlight Exposure (ASE). These two metrics allow a daylit space to be evaluated over the course of the year and provide significant direction for designers regarding the sufficiency of daylight illuminance available in a design. The first metric, spatial Daylight Autonomy (sDA), was established based upon Daylight Autonomy (Reinhart & Walkenhorst, 2001). The second metric, Annual Sunlight Exposure (ASE), was developed to suggest possible risks of excessive sunlight (Illuminating Engineering Society of North America & Daylight Metrics Committee, 2012). The following explains two metrics, spatial Daylight Autonomy (sDA) and Annual Sunlight Exposure (ASE), as described by the Illuminating Engineering Society.

Spatial Daylight Autonomy (sDA) Metric

Spatial Daylight Autonomy (sDA) is a metric that could best describe how much of a space receives sufficient daylight during standard working hours (8:00 a.m. - 6:00 p.m.) over the course of a year, based on using hourly illuminance grids on the horizontal work plane. It describes the percentage of the floor area that receives at least 300 lux for at least half of the annual occupied hours; as a result, sDA values can range from 0-100% of the floor area.

To qualify the acceptability of performance, two levels of criteria, “Preferred” and “Nominally Accepted”, were recognized. Daylight Autonomy 300/50% (sDA 300/50%) is recommended ‘preferred’ for analysis of daylight sufficiency when the percent of analysis points across the analysis area of 300 lux value for at least 50% of the analysis period exceed 75% of the analysis area. Also, “a space to be rated ‘nominally acceptable’ with regard to the sufficiency of the ambient daylight available, sDA 300, 50% must meet or exceed 55% of the analysis area” (Table 3) (Illuminating Engineering Society of North America & Daylight Metrics Committee, 2012, p. 2).

Table 3. "Preferred" and "Nominally Accepted" for sDA

“preferred”	sDA 300/50% >_ 75% of analysis area
“nominally accepted”	sDA 300/50% >_ 55% of analysis area

In addition to meeting the daylight sufficiency performance criteria above, successfully daylit spaces must also ensure the visual comfort of the occupants. Designers are encouraged to use multiple tools to assess and ensure the visual comfort of occupants under daylight conditions. One metric for the probability of visual discomfort is the number of hours that direct sunlight can potentially enter a space. This metric is called Annual Sunlight Exposure (ASE). ASE should be treated as one of multiple dimensions of daylight performance and as a check and balance to sDA, rather than as a standalone metric.

Annual Sun Exposure (ASE) Metric

Annual Sun Exposure (ASE) describes how much of a space receives too much direct sunlight, which can cause visual discomfort, glare, or increase cooling loads (too little daylight). ASE measures the percentage of floor area that exceeds the simulated value of 1000 lux for at least 250 occupied hours per year (Illuminating Engineering Society of North America & Daylight Metrics Committee, 2012). According to LM-83, if the ASE exceeds 10%, the space will have unsatisfactory visual comfort.

Each single metric could not sufficiently address all of the successful daylighting system factors for a whole daylit area or building over the course of a year. Maximizing sDA while keeping ASE in check is the goal of architects and stakeholders when designing buildings (Illuminating Engineering Society of North America & Daylight Metrics Committee, 2012). These new annual daylighting metrics and criteria need to be verified through several daylighting studies to increase designers' confidence so they can rely on them, enhance the adoption of annual climate-based daylight simulations in the future, and optimize daylighting design (Nezamdoost, 2015).

Leadership in Energy and Environmental Design (LEED) and Daylight

Leadership in Energy and Environmental Design (LEED) is the U.S. Green Building Rating System™ which consists of construction, operations, and maintenance guidelines for environmental evaluation of buildings and building design. LEED standards are an outline to design, operate and maintain green buildings and provide sustainable building performance. Increasing green building practices to achieve "environmentally responsible, profitable and healthy environments" for occupants of buildings was the main aim of LEED (Asmar et al., 2014, p.753). The reason for developing LEED was to address concerns about the negative environmental impacts that could be produced by buildings such as decreasing natural resources, increasing consumption of energy, and wasting production (U.S. Green Building Council, Inc., 2016).

In 2014, the latest version of LEED, version 4, codified sDA and ASE as one of two modeling compliance paths for Indoor Environmental Quality (EQ) Daylight Credit. LEED V4 offers more potential credits than the other compliance pathways. According to LEED V4, spaces are acceptable if they achieve at least 55% spatial Daylight Autonomy (sDA300 lux/50%time) and no more than 10% Annual Sunlight Exposure (ASE 1000 lux, 250hours). Thus, spaces achieve two points when annual computer simulations demonstrate sDA300/50% of at least 55% and ASE 1000, 250 of no more than 10%. Also, spaces can earn three points when annual computer simulations illustrate sDA300/50% of at least 75% with the same ASE 1000, 250 of no more than 10% (Illuminating Engineering Society of North America & Daylight Metrics Committee, 2012a; U.S. Green Building Council, Inc., 2015).

Goals of Daylight Availability in Open Plan Offices

Accordingly, the major goals of daylight availability are: 1) occupants' access to daylight, 2) harvesting daylight to reduce the use of electric lighting, 3) reaching an acceptable daylight uniformity across the workplace, 4) avoiding glare visual discomfort, and 5) preventing direct insolation, since it provides visual and thermal discomfort (DiLaura et al., 2011).

Table 4. Five Daylighting Goals

Daylighting Goals	Fundamental Daylighting Goals Critical to Layouts According to IES	1. Useable Interior Daylight That is Responsive to Daylight Access
		2. Daylight That Can Decrease the Amount of Electric Lighting Energy
		3. Reaching an Acceptable Daylight Balance Across the Workplace and Achieving a Comfortable View
	Most Common Problems a Daylight Space Must Avoid According to IES	1. Window Glare
		2. Direct Insolation That Creates Visual and Thermal Discomfort

This research plan was conducted to determine which partition height, material, orientation, and workstation layout in side-lit open office spaces provides the maximum amount of daylight (high sDA) with the minimum risk of excessive sunlight exposure (low ASE) in order to provide insight to the commercial building design community about the application of daylight in the development of future generations of office furniture. This study will be potentially beneficial to help the acceleration of interest among codes and standards organizations, manufacturers, interior designers, facility managers, and occupants regarding the impact and advantages of workstation partitions to provide sufficient daylight and visual comfort in open plan office spaces.

CHAPTER III

METHODOLOGY

The focus of this project is to customize and upgrade workstation partitions in an existing open plan office through simulated daylight results in order to bring the diffuse daylight into the interior environment and provide maximum occupant visual comfort and satisfaction. A comparative methodology is employed and 60 different scenarios are selected based on the previous literature review on partition features and lighting requirements in open plan offices. Daylight simulation is run to compare the potential annual variability of daylight in the study space. The simulation results are analyzed based on annual climate-based daylight metrics recommended by the Illuminating Engineering Society in the Lighting Measurements #83 (LM83) documentation, spatial Daylight Autonomy (sDA), and Annual Sunlight Exposure (ASE) during the annual occupied hours (8:00 A.M. – 6:00 P.M. / 10 hours). Finally, the results are codified by the latest version of US Green Building Council's (USGBC) LEED V4 rating system. Spaces through annual computer simulations could achieve two or three credits if spaces receive adequate diffuse daylight sufficiency and acceptable daylight excessiveness; at least 55% or 75% of floor area exceeds 300 lux for 50% of annual occupied hours (sDA) and no more than 10% of analysis points in a space exceeds 1000 lux of direct sunlight for 250 hours (ASE) as measured from 8:00 A.M. -6:00 P.M. (Illuminating Engineering Society of North America & Daylight Metrics Committee, 2012; U.S. Green Building Council, 2015).

Approach

A comparative methodology is conducted to develop concepts and data by coding and analysis (Taylor & Bogdan, 1998). Constant comparative methodology includes four stages: "(1) comparing incidents applicable to each category, (2) integrating categories and their properties, (3) delimiting the theory, and (4) writing the theory" (Glaser & Strauss, 1967, p.105). The advantage of utilizing this strategy is that the examination starts with raw information and a practical theory will develop based on constant evaluations (Glaser & Strauss, 1967). According to these four stages, the data is collected, analyzed, and coded in order to have a holistic evaluation of the proposed alternatives of workstation partitions based on daylight sufficiency and daylight excessiveness. This study will be potentially beneficial to help accelerate interest among codes and standards organizations, manufacturers, interior designers, facility managers, and occupants regarding the impacts and advantages of workstation partitions to provide sufficient daylight and visual comfort in open plan office spaces.

Research Question

This study is designed to explore:

- Which workstation partition and configuration ensures occupants' visual comfort and provides sufficient daylight in an existing side-lit open plan office?

Sub Questions

- How should workstation partition configuration be designed and arranged based on daily and annual sun position and the amount of daylight in each façade of the building (north, south, east and west)?
- How high should the partitions be designed in order to allow daylight to be well distributed into the space in each façade of the building?

Case Study

This paper examines a large-size open plan office on the 11th floor of a high rise building located in downtown Raleigh, NC. The case study has an area of approximately 2,579 m² (27,770 ft²). The windows have a head height of 2.64 m (8.69 ft) and the sill is at 0.2 m (0.69 ft); thus, the windows are 2.44 m (8 ft) tall. It was estimated that 125 occupants are on the 11th floor during regular working hours (from 8:00 A.M. - 6:00 P.M., Monday through Friday). The building's rotation is 5° clockwise from the North axis. The building orientation receives a large amount of morning and afternoon exposure. It also receives more light in summer, making it difficult to shade in direct sunlight. The latitude of Raleigh, NC is 35° 46' 28. 72"N, and the longitude is 78° 38' 21.85"W (Figures 7, 8, 9, and 10). Simulations were conducted with a typical meteorological year (TMY3) dataset for Raleigh, NC, instead of extreme weather conditions of an actual weather year: “Typical Meteorological Year (TMY) formatted hourly weather data involves hourly averages, with data centered on the half-hour” (Illuminating Engineering Society of North America & Daylight Metrics Committee, 2012).

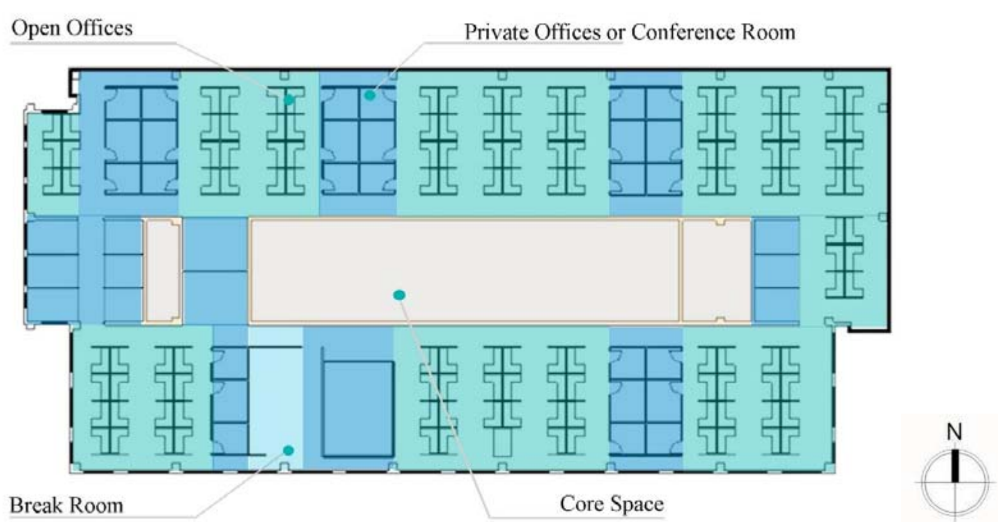


Figure 7. Existing Plan of Case Study- 130 Workstations

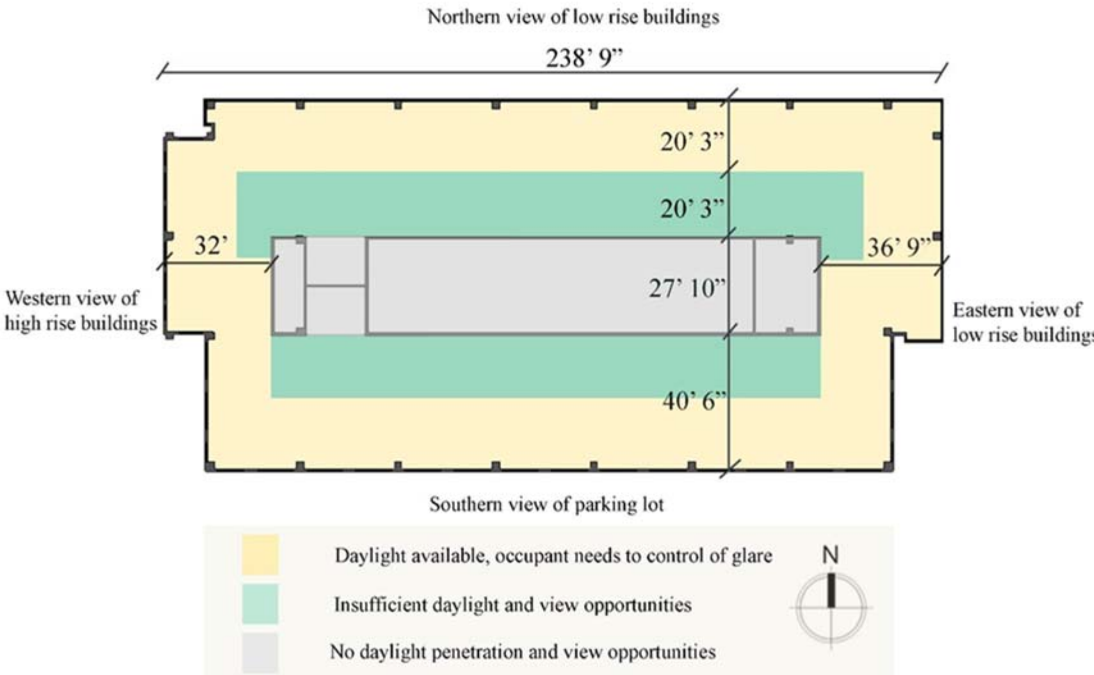


Figure 8. Case Study- Dimension & Daylighting Opportunity Analysis

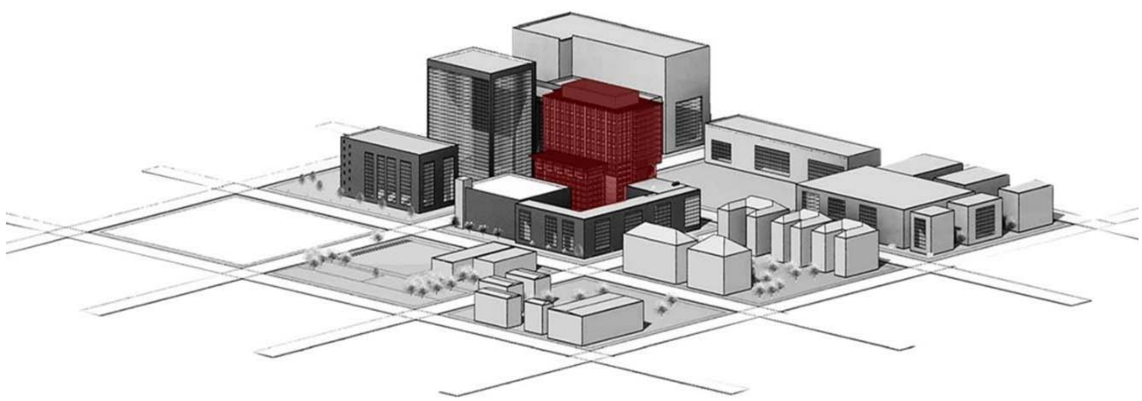


Figure 9. Case Study Building- Bird's Eye View

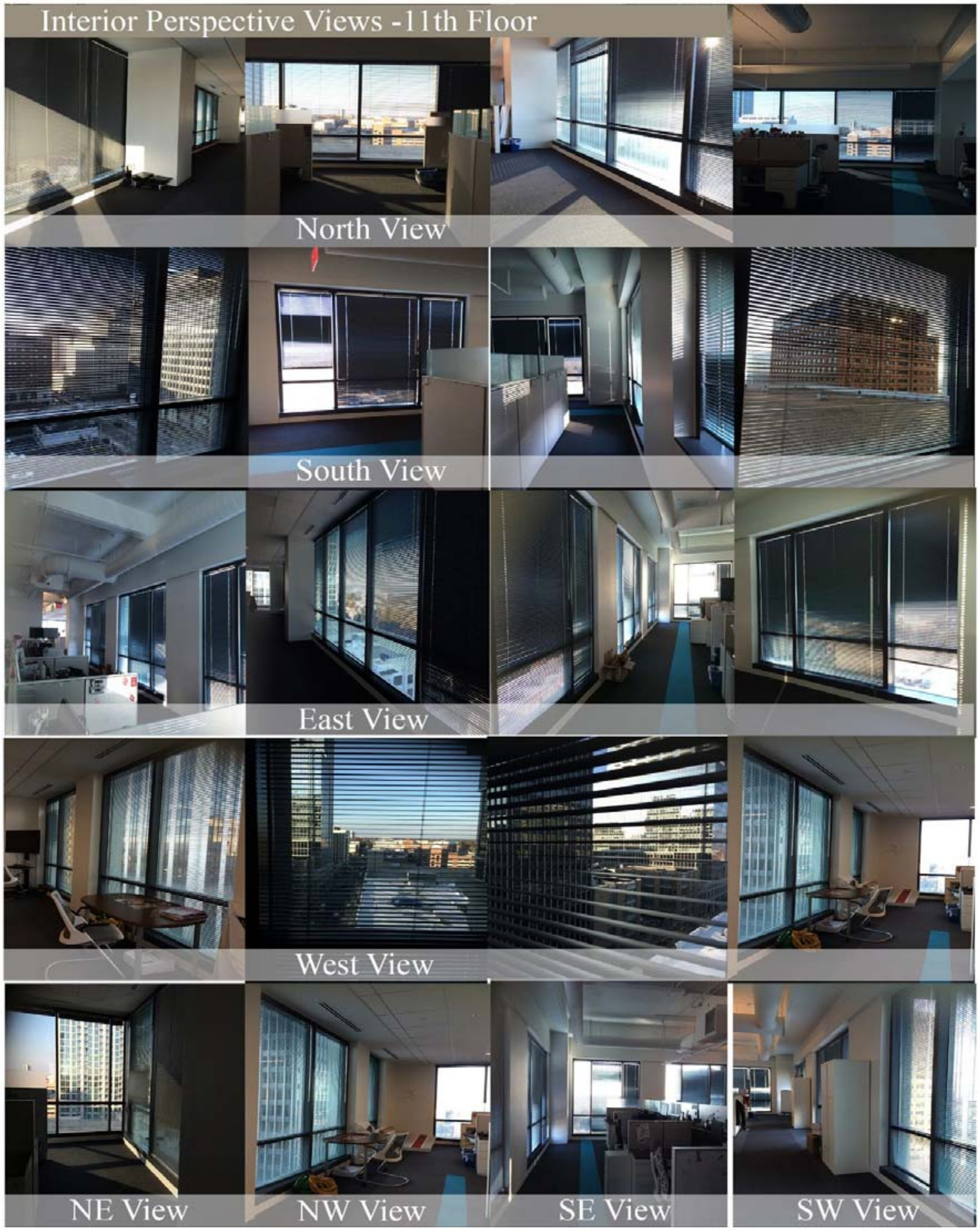


Figure 10. Case Study Building- Interior Spaces.
Image Credit- Author

Table 5. Experimental Variables

Independent Variables	Space Orientation (North, South, East, West) Partition Height (42”, 48”, 60”) Partition Material (Opaque, Translucent, Transparent) Partition Direction (Parallel or Perpendicular) Partition Layout (Spine or Bridge Layout)
Dependent Variables	Daylight Availability

Climate - Raleigh, North Carolina

As shown in Table 6, almost one third of the climate in Raleigh, North Carolina is sunny (the sky is mostly clear or with clouds covering up to 30% of the sky during daylight hours). The other one third of annual days are partly sunny (clouds cover between 40% to 70% of the sky). It is also demonstrated in the US regional patterns of cloud cover in Figure 11 that there are 150 to 180 cloudy days a year in Raleigh, NC.

Table 6. Annual Days of Sunshine in Raleigh, NC

Annual Days of Sunshine	Sunny	Partly Sunny	Total Days with Sun
	111	106	217
Percent of Sunshine Yearly	58% Sun		

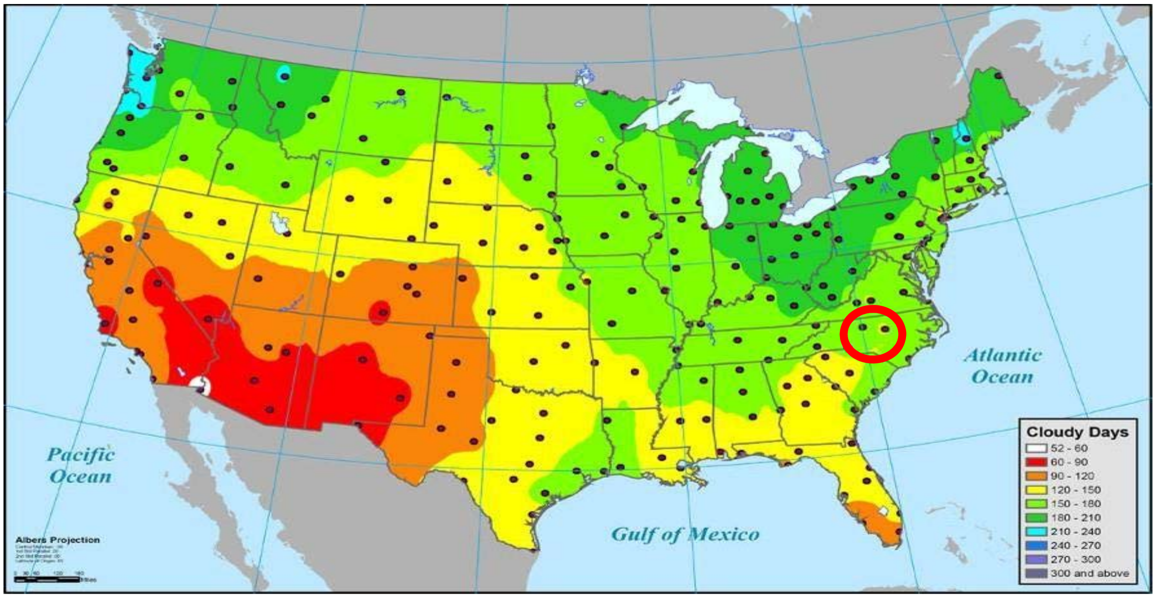


Figure 11. Regional Patterns of Cloud Cover/ Raleigh, NC

Exterior Obstructions

The amount of daylight that enters into a space depends on external obstructions surrounding the study space such as trees and other buildings. As shown in Figure 12, the high rise buildings in the west, north-west, and south-west of a construction site create an obstruction and may reduce daylight availability in different hours of daytime. They could also reflect sunlight that might cause glare and visual discomfort in the building. However, in this case the surrounding buildings do not have any substantial impact on the amount of daylight available due to the height of the 11th floor from the ground (120 SF), the orientation of the building, and its distance from other buildings.

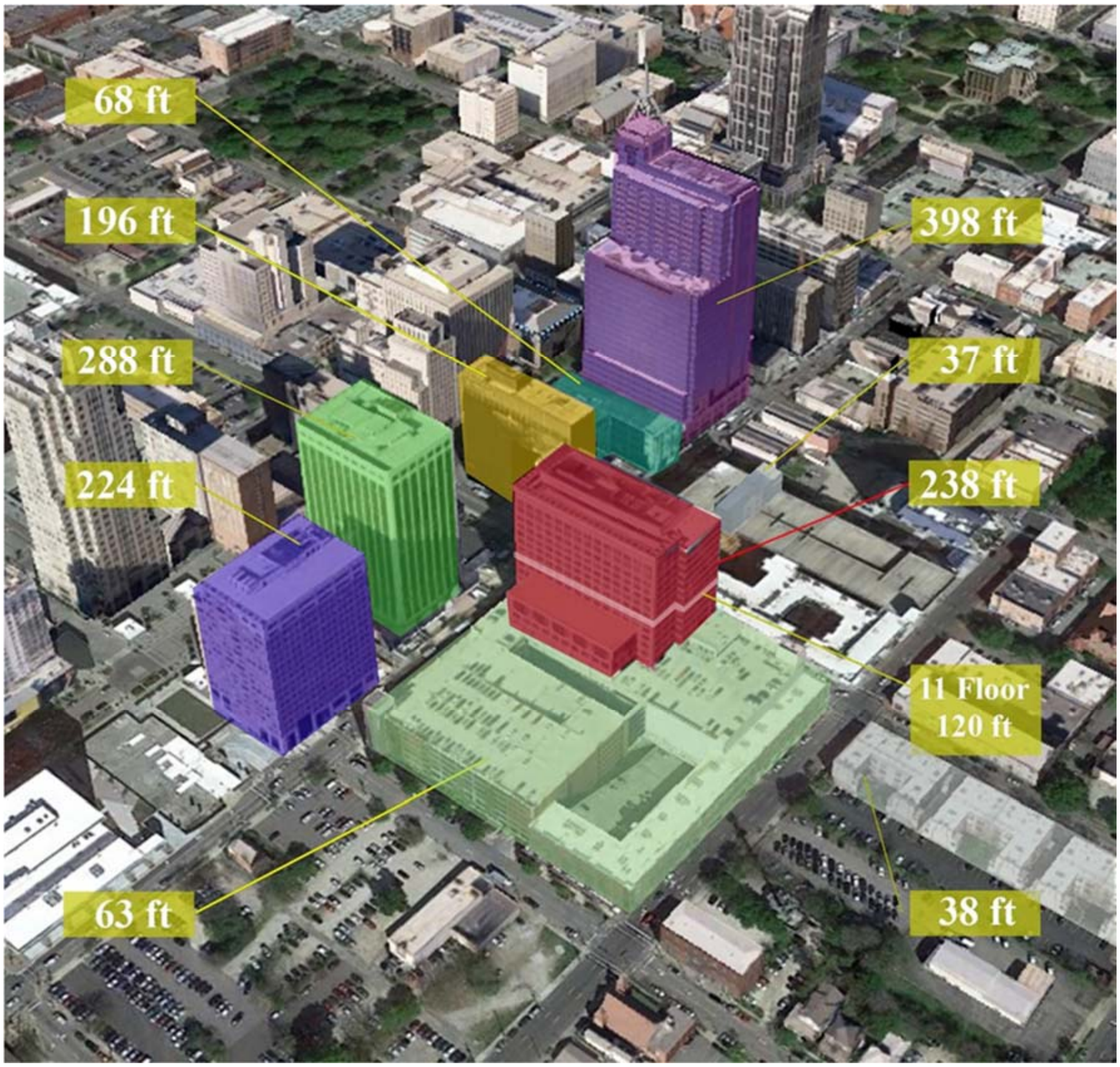


Figure 12. Exterior Obstructions

Data Collection: Daylight Simulation

Five workstation furniture layouts (desks perpendicular to windows-bridge layout, desks parallel to windows-bridge layout, desks parallel to windows-spine layout, and two different alternatives of desks perpendicular to windows-spine layout) and 60 alternate combinations of partitions based on four variables including partitions' height, material, layout, and direction to the window are illustrated in Table 7. Daylight simulation is conducted for all 60 scenarios of partition design and zone-by-zone, each orientation (north, south, east, and west) of 60 scenarios, by a three phase RADIANCE daylight engine (V. 4. 2. 0). Finally, simulation results will be compared with two baselines: without furniture and with an existing furniture layout.

Table 7. Comparative Study- 60 Partition Design Scenarios

Materials	**Opaque Partition (20% Reflection)** **Translucent Partition (50% LT)** **Translucent Partition (20% LT)** **Transparent Partition (50% VLT)** **Transparent Partition (30% VLT)**	**Heights**	**42”** **48”** **60”**
Orientations	Desks Parallel to Windows Desks Perpendicular to Windows	Layouts	Bridge Layout Spine Layout
60 Partition Design Scenarios			

Layout #1

Desks Perpendicular to Windows-Bridge Layout (189 Workstations Partitions): Layout One is a bridge layout with 189 desks perpendicular to windows. The Bridge Layout includes modular cabinets with the role of screening workstations from the corridor and neighboring desks. It is possible to create large sized workstations by extending the worksurface with the open shelf of a cabinet. Bridge layouts work to focus both groups and teamwork, as is shown in Figure 13. Moreover, taller partitions (48” or greater) provide privacy and create a sense of enclosure. They should be oriented perpendicular to the window wall; accordingly, they do not block the direction of the daylight and maintain views to the exterior. Desks perpendicular to windows create the most comfortable setting. The alternative of the window to the side of desk is well illuminated and the source is not in the direct line of sight. For instance, the direction most occupants face while performing visual tasks (i.e. looking at a computer) is perpendicular to daylight openings. This helps avoid the visual discomfort occupants experience when looking into their shadow, or worse, from the excessive contrast occurring when a visual task area is immediately surrounded by the brightness of a view to the exterior.

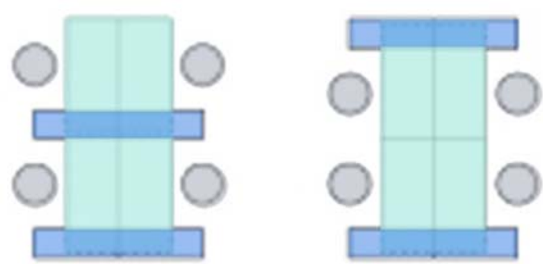


Figure 13. Bridge Layout

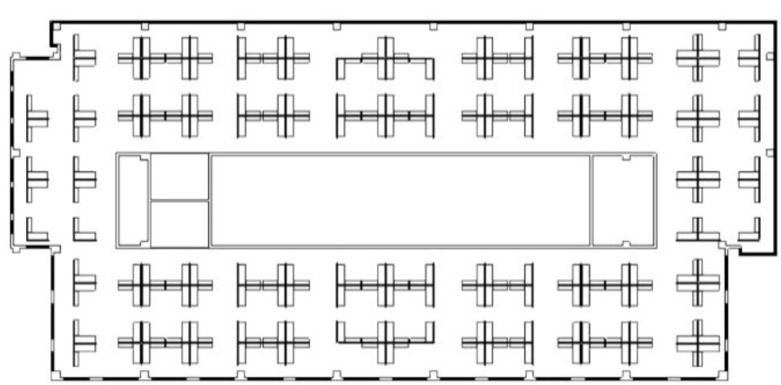


Figure 14. Layout #1: Desks Perpendicular to Windows-Bridge Layout

Layout #2

Desks Parallel to Windows-Bridge Layout (152 Workstations Partitions): Layout Two, similar to Layout One, is the Bridge Layout, but desks are parallel to windows and there are 152 workstations in this layout. The direction of the desks are parallel to windows to ensure the maintenance of views to the outside. However, facing the bright window creates a harsh contrast in comparison to a relatively dark task and it is extremely tiring for the eye to have both the window and task in view. Likewise, if an occupant is sitting with their back to the window, the task may be shaded and too dark to see easily and the computer screen may be difficult to see if it reflects light.

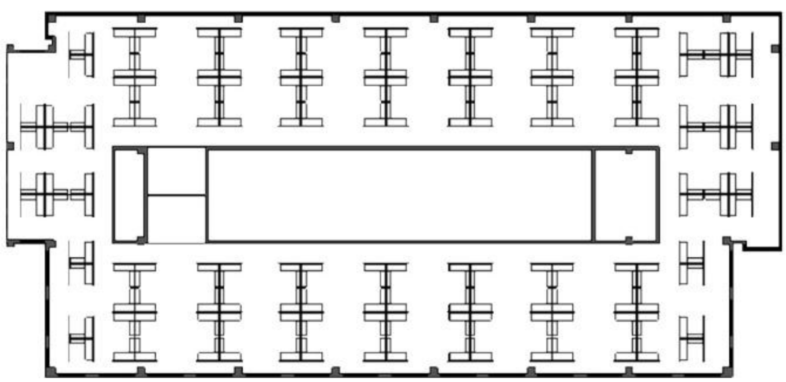


Figure 15. Layout #2: Desks Parallel to Windows-Bridge Layout

Layout #3

Desks Parallel to Windows-Spine Layout (189 Workstations Partitions): Layout Three is the Spine Layout with desks parallel to windows and 189 workstations. A Spine Layout consists of a main aisle used for the typical movements between the work cells located on both sides and for the temporary storage of work in process. The modular center cabinet in the middle of the work cells is implemented to connect all the perpendicular work surfaces, as shown in Figure 16. Layout Three, similar to Layout Two, is parallel to the windows and there are 189 workstations in this layout.

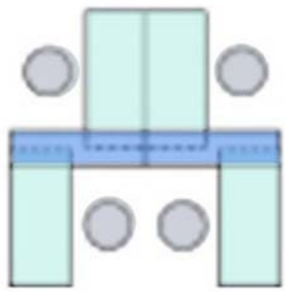


Figure 16. Spine Layout

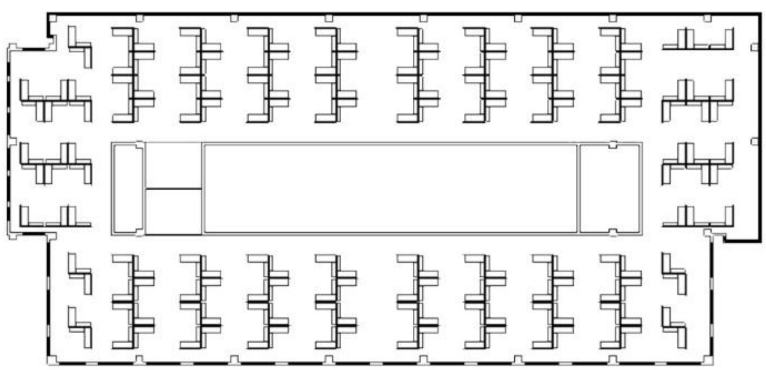


Figure 17. Layout #3: Desks Parallel to Windows-Spine Layout

Layouts #4- #5

Desks Perpendicular to Windows-Spine Layout (187 Workstations Partitions): Layouts Four and Five are similar to Layout Three with the Spine Layout but desks are perpendicular to windows with 187 and 143 workstations, respectively. Two different alternatives are selected to evaluate the amount of daylight in the different shape of workstations (#4) and similar shape of workstations (#5) behind each other in two rows.

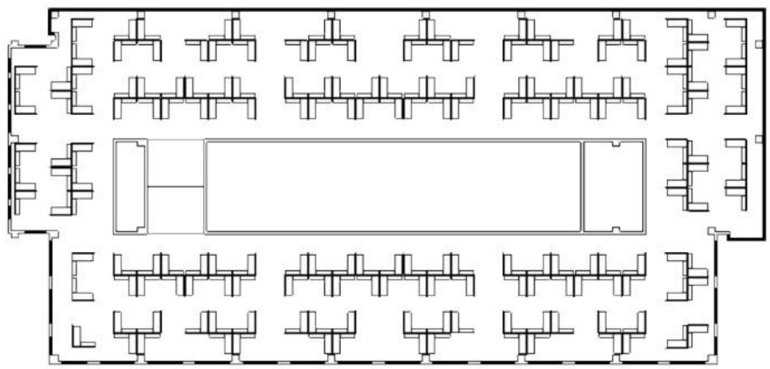


Figure 18. Layout #4: Desks Perpendicular to Windows-Spine Layout

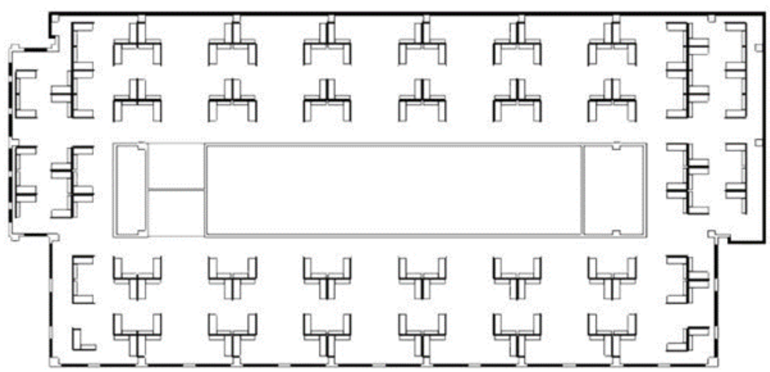


Figure 19. Layout #5: Desks Perpendicular to Windows-Spine Layout

Open Plan Daylighting Zones

This study is conducted in order to compare 60 alternate workstation partition designs in four daylight zones (north, south, east, and west). Building orientation is a substantial factor in workstation partition design consideration due to the dynamic position of the sun during the course of the day and the year which causes dissimilar luminous conditions in different orientations. The design of effective workstation partitions depends on the solar orientation of a particular window. In the northern façade, there is no direct sunlight at any point in the day, so this orientation receives a large amount of daylight with minimal solar heat gains. In the southern façade, there is good access to strong illumination (the original source) and it is an excellent source of natural daylight, although it varies through the day and the year. The western façade and the eastern façade should have greatly minimized windows due to excessive solar heat gain and intense glare issues, especially with lower altitude sun angles throughout the year in the late afternoon and evening. Moreover, according to IES LM-83 2012, documentation analysis areas shall be considered by façade orientation, and never exceed 10,000 sf. Given that, the entire floor plate is broken down into four daylight zones below 10,000 sf, shown on Figure 20, and the amount of daylight is analyzed based on the zoning of spaces and window groups in the annual simulations.

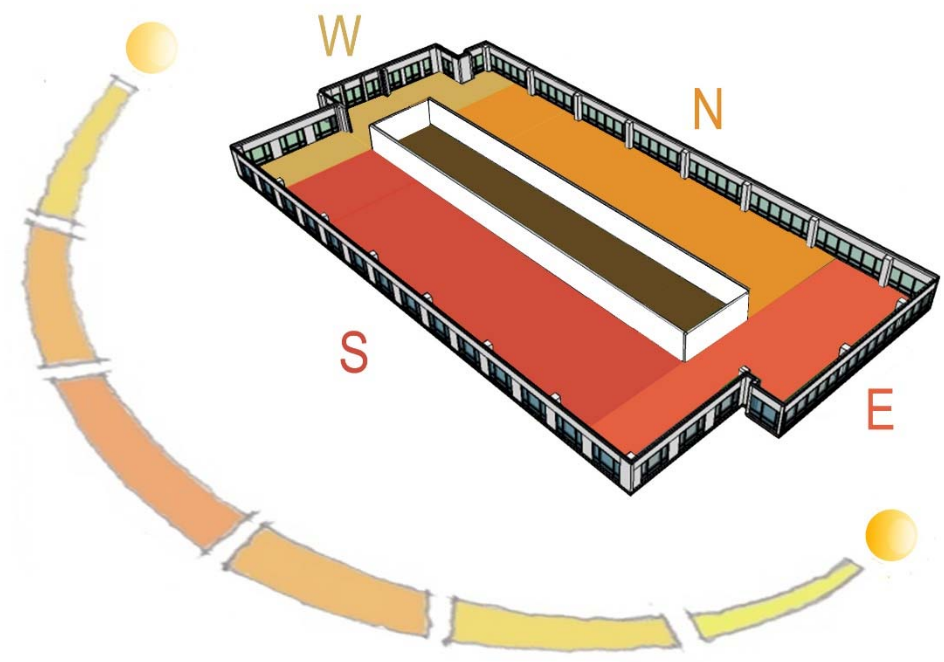


Figure 20. Generic Floor Plan - Location of Open Plan Daylighting Zones

Simulation Parameters

For annual climate-based daylight simulation, detailed digital interior models are generated in Sketch Up 2015. The simulation protocol outlined in LM-83 (Illuminating Engineering Society of North America & Daylight Metrics Committee, 2012) is used. When the model is completed and verified for accuracy against floor plans, photographs, and Google Earth, it is exported to the RADIANCE daylight simulation engine. The RADIANCE daylight engine is a computer simulation analysis software for modeling and visualizing lighting and the annual amount of daylight in and around architectural environments. It is known to provide a higher level of accuracy in predicting levels of daylight illuminance compared with a number of other daylighting software packages and is beneficial for determining whether or not there is sufficient light to accomplish different activities. In RADIANCE, to calculate light source contributions, we use Rcontrib ambient calculations. In this case study, an illuminance analysis grid of 2’x2’ was used (4884 analysis points) for generating illuminance point data, as shown in Figure 22.

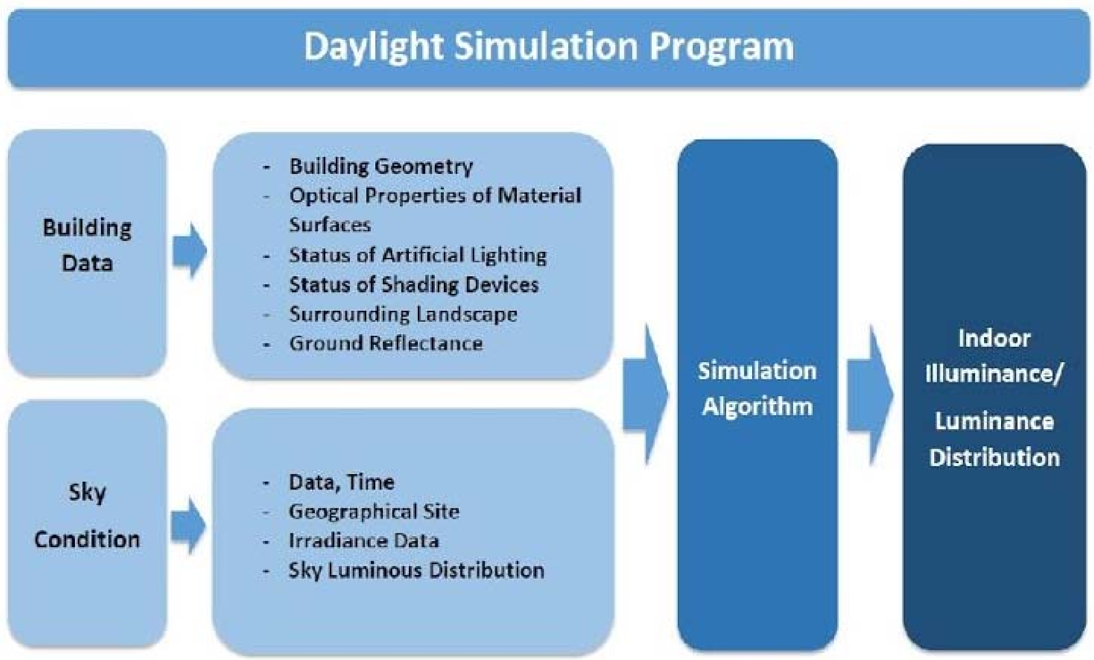


Figure 21. Indoor Illuminance Calculation through Daylight Simulation Tool By Reinhart (2001)

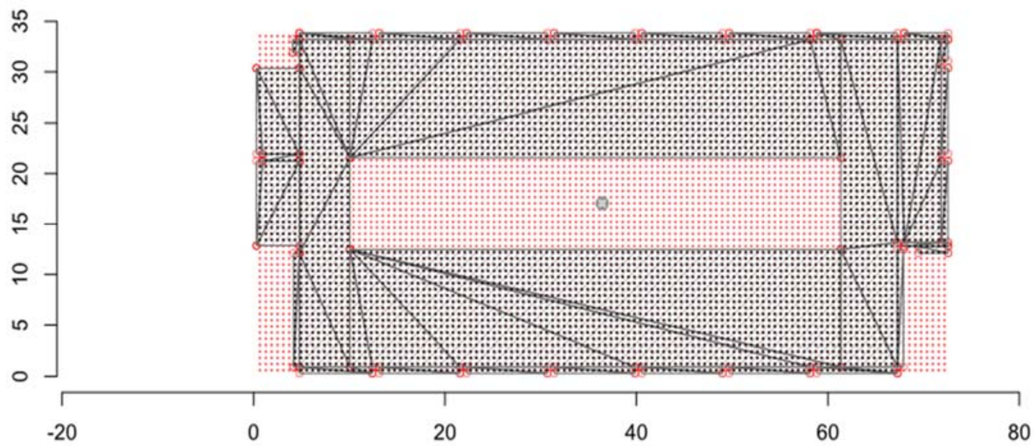


Figure 22. Grid Points Plot

Likewise, interior surface reflection is assigned to digital models based on the information from construction specifications and field measurements: 10% floor, 50% wall, 60% ceiling, and 50% furniture. The data represented in the analysis model considers the raw architectural geometry with no blind operations. The blinds are supposed to be open during the day regardless of sun position or sky condition.

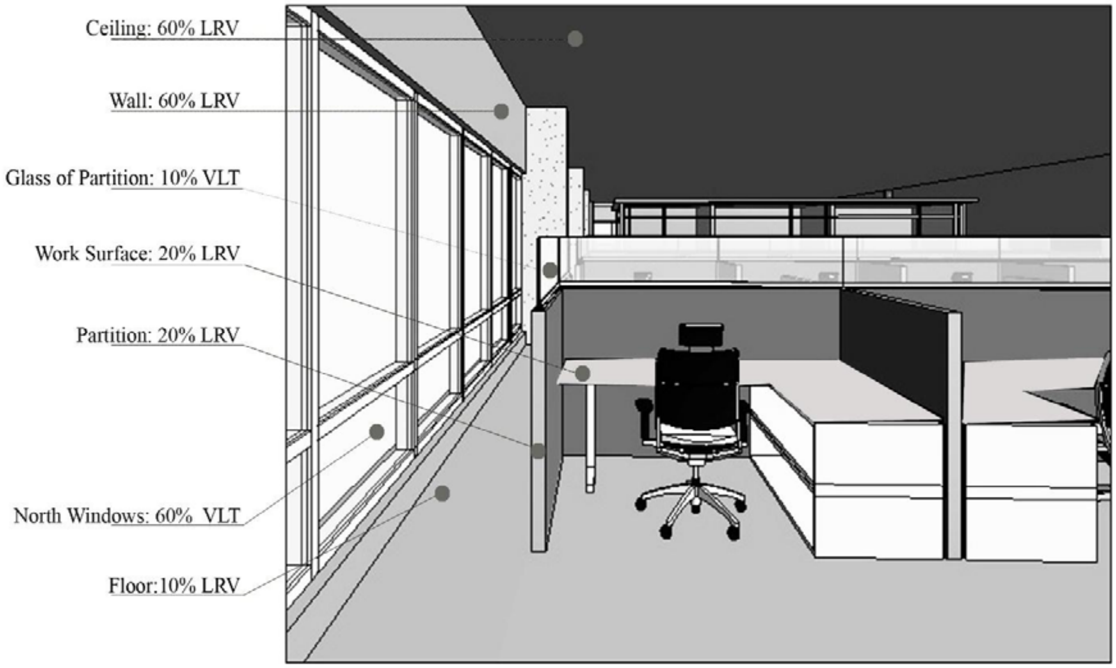


Figure 23. Interior Surface Reflection.
Image Credit- Author

Since the goal of the simulations is to predict annual daylighting conditions in the study space over the course of a full year, the typical meteorological year (TMY) information was used to provide a closer type of professional practice that would actually be used in several metrics. The use of actual weather information might have caused tighter calibration of the computer model. Table 8 summarizes all simulation parameters.

Table 8. The Simulation Parameters

Software	RADIANCE- Daylight Simulation Engine (V.4.2.0)	
Times of the Day	Annual-Occupied Hours (8:00 A.M.-6:00 P.M.)	
Climate	Typical Meteorological Year (TMY)-Raleigh NC	
% Visible Light Transmission - Windows	60% Visible Light Transmission - North Windows	
	50% Visible Light Transmission - South Windows	
	30% Visible Light Transmission - West Windows	
	60% Visible Light Transmission - East Windows	
Interior Surfaces (Existing)	60% Wall Light Reflection Value	
	60% Ceiling Light Reflection Value	
	10% Floor Light Reflection Value	
	20% Partition/Work Surface Light Reflection Value	
	10% Visible Light Transmission- Glass of Partition	
Interior Surfaces (As Designed)	Same Reflection for Windows, Walls, Ceiling, Floor	
	Opaque Partition	20% Reflection
	Translucent Partition	50% Light Transmittance
	Translucent Partition	20% Light Transmittance
	Transparent Partition	50% Visible Light Transmission
	Transparent Partition	30% Visible Light Transmission

Coding and Analysis

In order to provide a relevant basis of comparison between the 60 proposed workstation partitions, simulation results were analyzed based on two recently recommended annual climate-based daylighting metrics and performance criteria proposed by IES 2012: spatial Daylight Autonomy (sDA) and Annual Sunlight Exposure (ASE). These two metrics allow a daylit space to be evaluated for a one-year period using two different performance parameters: sufficiency of daylight illuminance (sDA) and the potential risk of excessive sunlight penetration (ASE) (Illuminating Engineering Society of North America & Daylight Metrics Committee, 2012). A comparative study will be conducted based on the maximum value of daylight sufficiency, minimum glare, and visual discomfort (highest sDA value and lowest ASE value). In other words, the sDA and ASE values of each partition layout alternative will be sorted from the most daylit (highest sDA and lowest ASE percentage) to the least daylit (lowest sDA and highest ASE percentage), and then will be prioritized based on LEED V4 EQ daylight credit points.

Figure 24. Examples of Simulation Results (DA Plot, Left and ASE Plot, Right)

Table 9. LEED V4 Indoor Environmental Quality Daylight Credit

Point	sDA	ASE
2	Above 55%	Below 10%
3	Above 75%	Below 10%

CHAPTER IV

RESULTS

This chapter reports the findings of the comparison study conducted between 60 alternate workstation partition layouts (as shown in Table 7) based on annual climate-based daylighting simulation in a large open plan office on the 11th floor of a high-rise building, located in downtown Raleigh, NC. Four daylight zones (north, south, east, and west) determine which workstation partition provides a more diffuse daylight sufficiency and reduces excessive daylight in each direction of open plan office spaces based on the height, orientations, layout, and materiality of the partitions (reflective surfaces of partitions). In order to test this idea, the daylight simulations were run in the existing plan with and without furniture.

Simulation results based on the existing furniture design show only 50.08% daylight sufficiency and 10.91% daylight excessiveness; while these numbers without furniture are different, 97.48% and 15.41%, respectively, it shows the robust impact of furniture design in the open plan office spaces. In the existing plan with furniture, given the placement and location of workstations, less daylight comes into the space and thereby lowers sDA value and increases ASE value as it is shown in Figure 25. Daylight

Autonomy (DA) is represented as a percentage of the floor area that receives at least 300 lux for at least 50% of the annual occupied hours. The green, yellow, and red in sDA plots represent the area which 50% of time receives at least 300 lux; based on IES LM-83 documentation it would be considered a daylit area. The blue zones represent the area below 50% of the time and it would be considered a non-daylit area based on IES LM-83 documentation. In ASE plots, those areas achieve 1000 lux for more than 250 occupied hours (8:00 A.M. – 6:00 P.M.) during a year, which are unacceptable due to glare potential daylight excessiveness. It is illustrated in dark yellow while light yellow shows those floor areas that achieve 1000 lux for less than 250 occupied hours of the year.

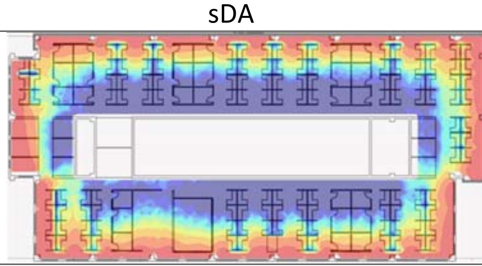
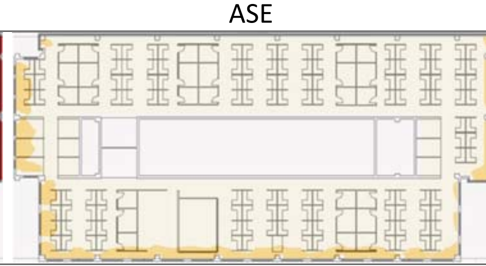
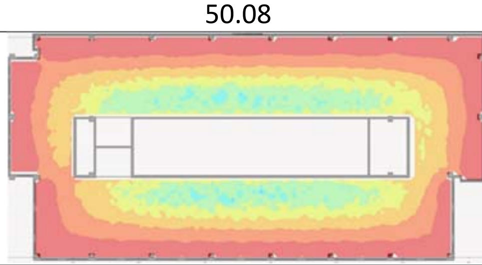
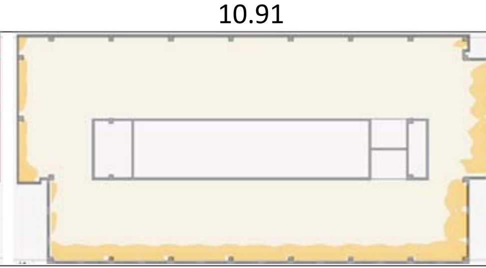
Existing Plan		
(Windows in North & East: 60% VLT, Windows in South: 50% VLT, Windows in West: 30% VLT)		
	sDA	ASE
With Furniture		
	50.08	10.91
Without Furniture		
	97.48	15.41

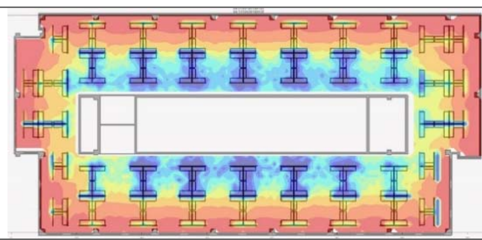
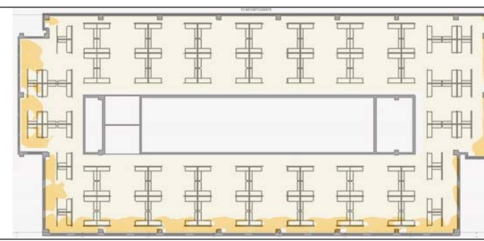
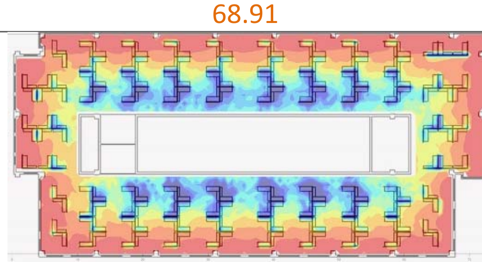
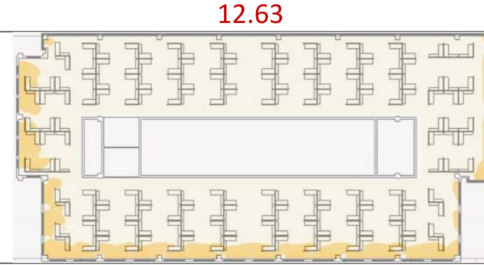
Figure 25. Simulation Plots – Existing Plan

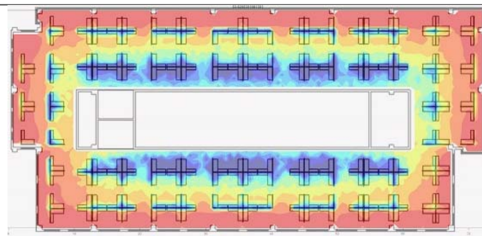
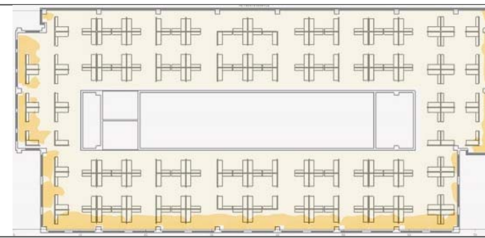
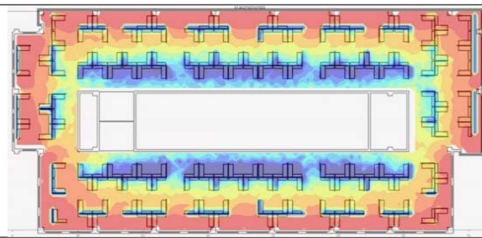
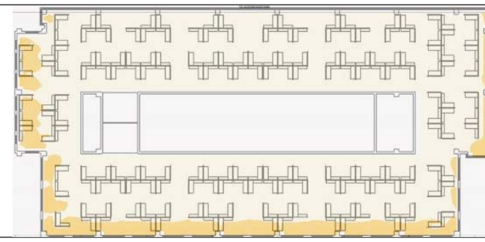
The following section compares the results of 60 scenarios of partition designs and initial explorations with the output of the simulations. To simplify the results, they were divided based on three different materials of partitions:

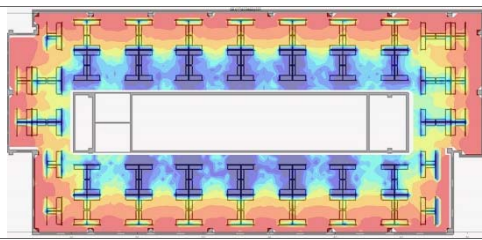
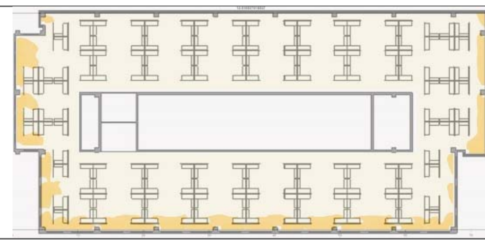
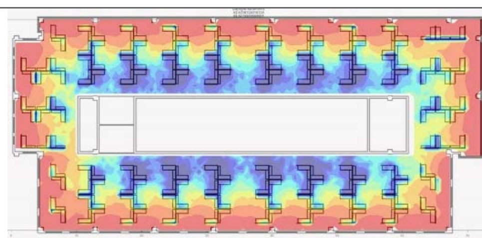
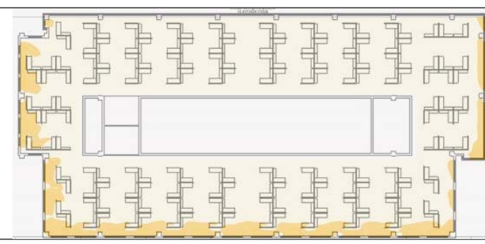
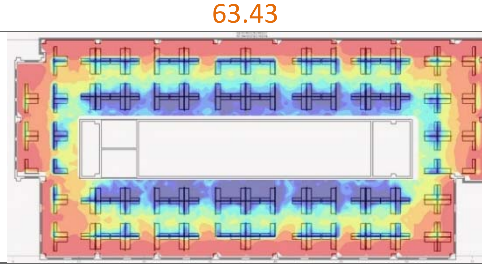
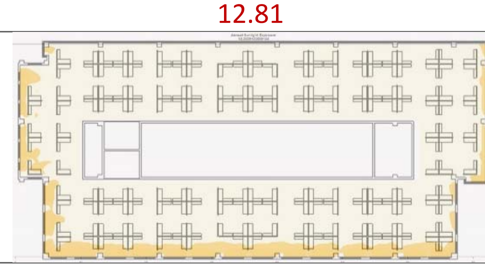
- Opaque partitions (Reflection 20%) with 42”, 48”, or 60” height in parallel or perpendicular orientation to windows based on bridge or spine layouts (12 sDA and ASE plots).
- Translucent partitions in two different light transmittance values (20% and 50%) with 42”, 48”, or 60” height in parallel or perpendicular orientation to windows based on bridge or spine layouts (24 sDA and ASE plots).
- Transparent partitions in two different visible light transmittance values (30% and 50%) with 42”, 48”, or 60” height in parallel or perpendicular orientation to windows based on bridge or spine layouts (24 sDA and ASE plots).

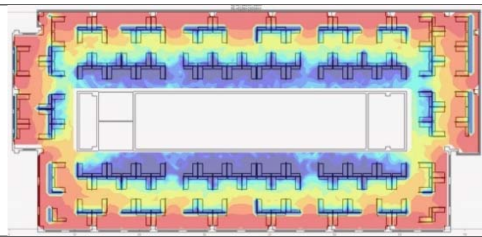
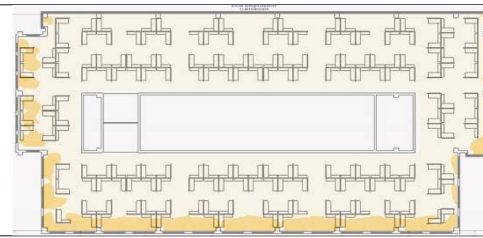
The daylight availability and excessiveness based on opaque partitions (20% Reflection) were calculated through simulation and plotted in Figure 26. Opaque partitions (20% Reflection) with 60” height considerably prevent daylight from entering into the space in different partition orientations (perpendicular and parallel) and partition layouts (spine and bridge). This means that small portions of the floor area exceed 300 lux for 50% of annual occupied hours, which even got worse in perpendicular partition orientation with almost 46% annual daylight sufficiency while in parallel partition orientation sDA values are higher, around 53%. The results of opaque partitions (20% Reflection) with 42” and 48” height do not show any considerable discrepancy in the sDA values by altering the orientations and layout of partitions.

In opaque partitions (20% Reflection), the highest annual daylight sufficiency values were recorded for 42” height in perpendicular partition orientation to windows based on bridge layouts (71.04 %). As it was expected, by increasing the partition height, the amount of daylight that enters into the space reduces which consequently decreases the number of hours that the floor area achieves 1000 lux during occupied hours. Figure 26 compares the impacts of opaque partitions in different heights, orientations, and layouts in the case study building with opaque partitions using sDA and ASE simulation plots.

	Opaque Partitions (20% Reflection)	
42”	sDA	ASE
Para - BL		
	68.91	12.63
Para - SL		
	70.72	13.41

Per - BL		
	71.04	13.18
Per - SL		
	69.30	13.45

48”	sDA	ASE
Para - BL		
	62.16	12.01
Para - SL		
	63.43	12.81
Per - BL		
	62.67	12.30

Per - SL		
	62.40	13.00

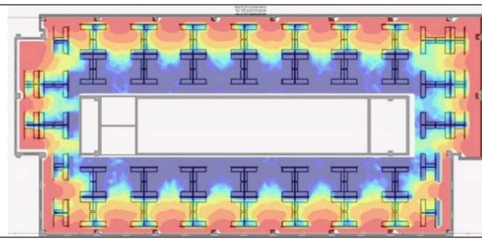
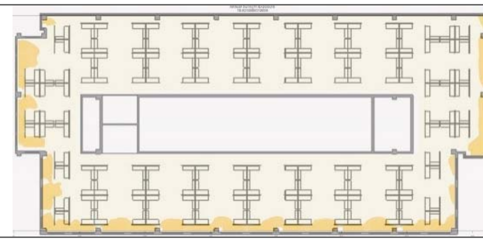
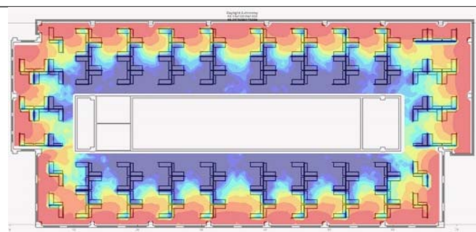
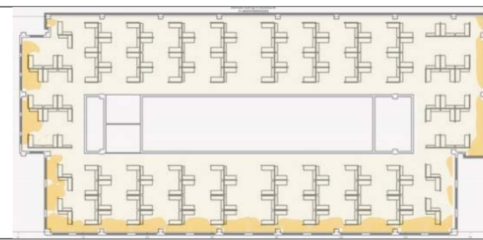
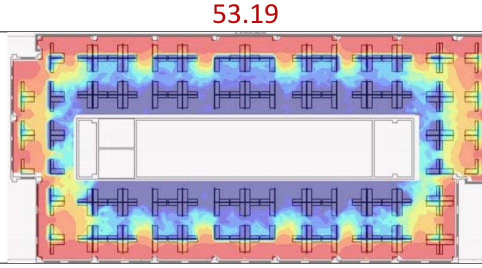
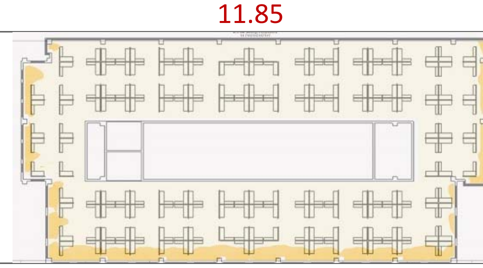
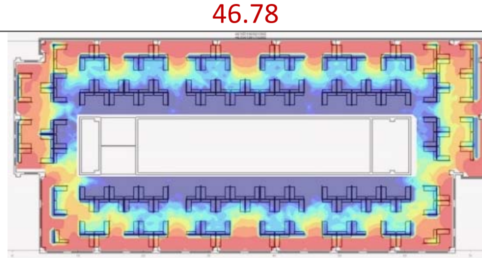
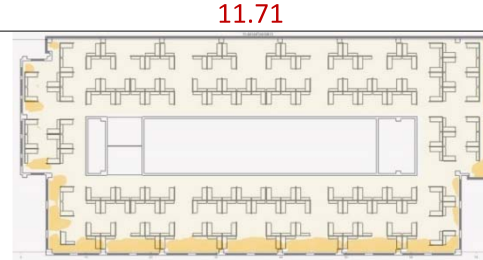
60”	sDA	ASE
Para - BL		
	53.76	10.83
Para - SL		
	53.19	11.85
Per - BL		
	46.78	11.71
Per - SL		
	46.56	11.26

Figure 26. Simulation Plots - Opaque Partitions (20% Reflection)

As shown in Table 10, in the north and south façades the sDA values are relatively low (mostly below 50%) regardless of partition orientation and layout. Conversely, in the east and west façades, high values were recorded for sDA, 77.49% and 115.86% in average respectively. As expected, partition height in all orientations shows the most robust factor on daylight availability in the study space. It can be clearly figured by comparing total sDA values in Table 10.

Regarding ASE values, no considerable values were reported on the north façade since no direct sunlight penetrates into the space. The ASE values recorded on the east side of the building are too unresponsive (from 16.25% to 17.08%) to the partition height, orientation, and layout. The ASE values on west and south sides show more sensitivity and variation based upon different partition heights, orientations, and layouts. On the south façade, opaque partitions oriented parallel to the windows based upon bridge layouts blocks sunlight more than other alternatives (1.8% lower ASE average than the total south ASE average), while perpendicular partitions respond better in reducing direct sunlight.

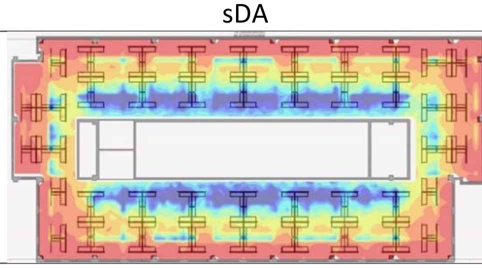
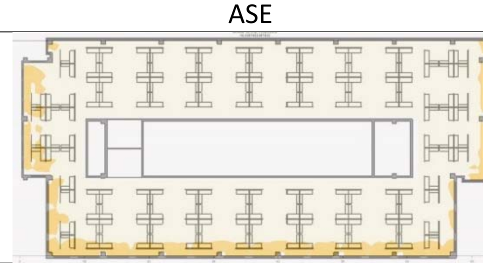
Table 10. Simulation Results (sDA-ASE) - Opaque Partitions (20% Reflection)

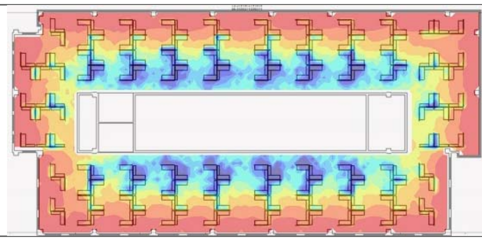
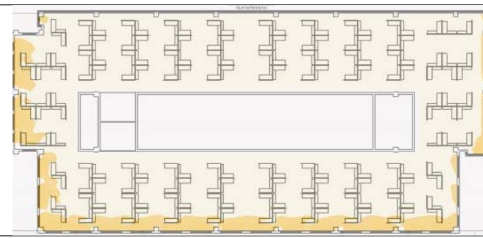
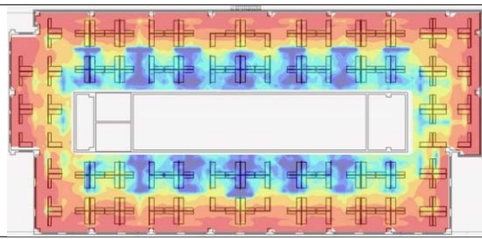
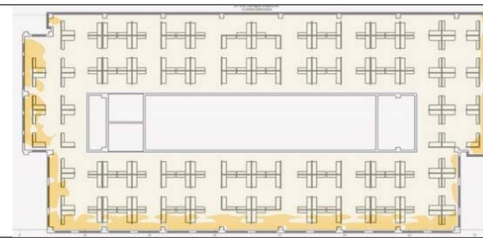
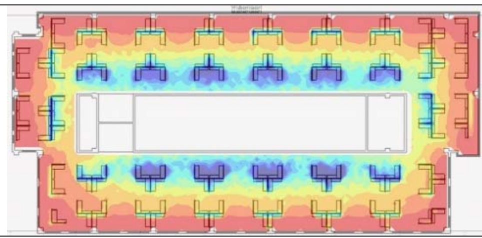
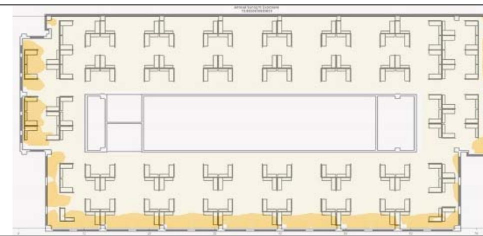
Opaque (20% Ref)	Para-BL 42"	Para-SL 42"	Per-BL 42"	Per-SL 42"	Para-BL 48"	Para-SL 48"	Per-BL 48"	Per-SL 48"	Para-BL 60"	Para-SL 60"	Per-BL 60"	Per-SL 60"
N	49.67	50.27	51.18	53.29	44.41	42.48	37.52	45.50	38.13	36.13	29.42	32.15
S	54.20	52.82	53.56	57.70	48.28	46.63	41.48	50.45	40.52	39.31	33.08	36.26
E	86.37	86.96	87.66	85.90	76.73	78.26	80.61	80.38	63.22	69.10	68.51	66.27
W	94.51	97.41	98.48	97.87	92.99	96.04	94.97	92.38	82.62	85.82	85.06	81.86
Total	68.91	70.72	71.04	69.30	62.16	63.43	62.67	62.40	53.76	53.19	46.78	46.56

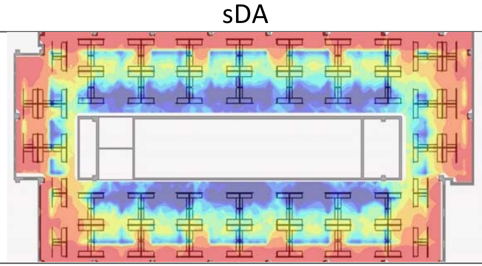
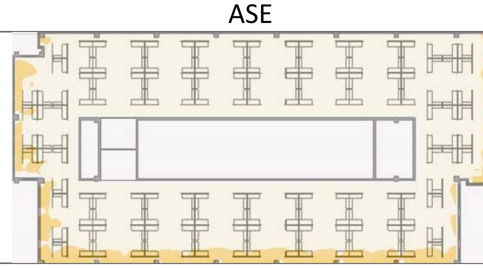
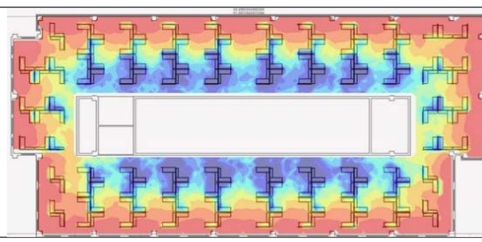
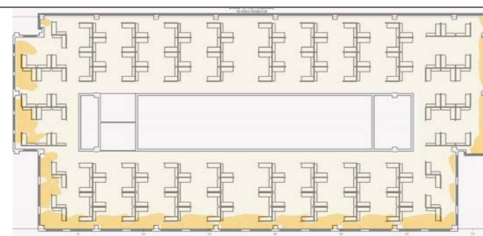
Opaque (20% Ref)	Para-BL 42"	Para-SL 42"	Per-BL 42"	Per-SL 42"	Para-BL 48"	Para-SL 48"	Per-BL 48"	Per-SL 48"	Para-BL 60"	Para-SL 60"	Per-BL 60"	Per-SL 60"
N	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S	17.13	17.96	18.41	18.54	15.03	16.37	17.45	17.96	12.42	14.46	16.88	17.32
E	17.08	17.08	16.84	16.96	16.96	16.96	16.49	16.48	16.61	16.84	16.25	16.37
W	25.92	26.76	24.31	27.68	24.16	24.92	22.17	24.92	22.63	22.71	20.03	15.60
Total	12.63	13.41	13.18	13.45	12.01	12.81	12.30	13.00	10.83	11.85	11.71	11.26

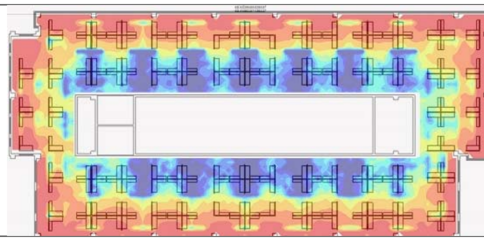
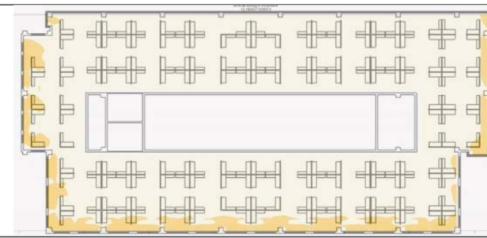
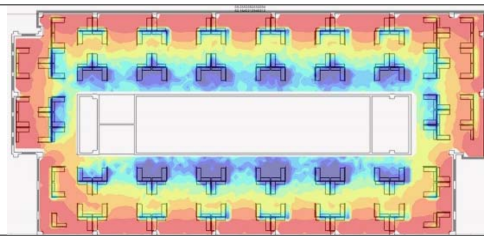
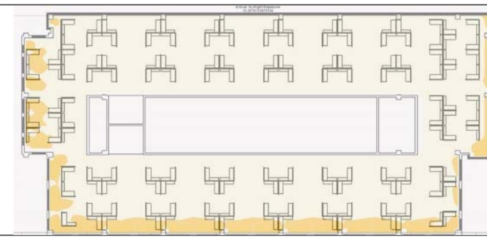
Also analyzed were the impacts of different partition materials with different transparency and reflectance values on daylight availability and daylight excessiveness. Translucent partitions with 20% and 50% light transmittance values were analyzed through simulation and plotted in Figures 27 and 28.

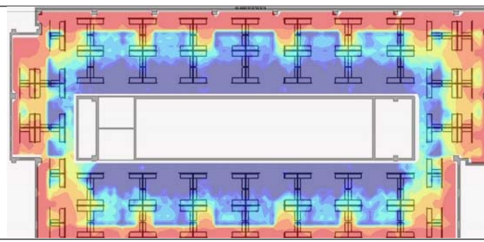
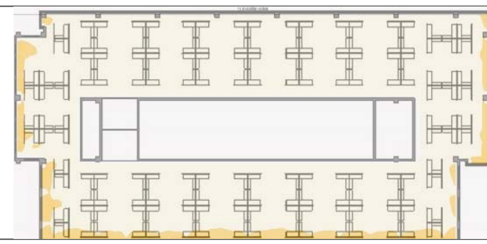
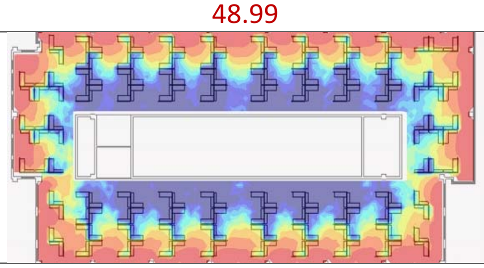
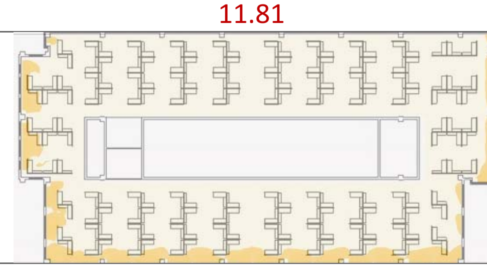
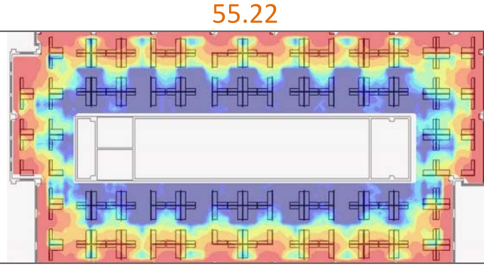
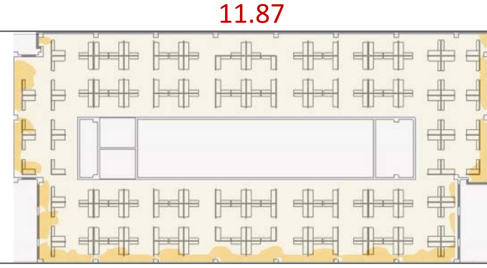
Translucent Partitions (20% Light Transmittance)

42”	sDA	ASE
Para - BL		
	74.32	13.30

Para - SL		
	72.37	13.51
Per - BL		
	71.35	12.89
Per - SL		
	77.10	13.88

48”	sDA	ASE
Para - BL		
	65.72	12.61
Para - SL		
	65.49	12.85

Per - BL		
	65.68	12.18
Per - SL		
	69.36	13.26

60”	sDA	ASE
Para - BL		
	48.99	11.81
Para - SL		
	55.22	11.87
Per - BL		
	57.35	10.58

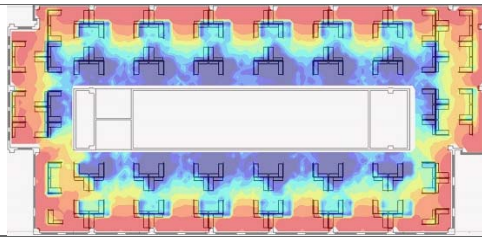
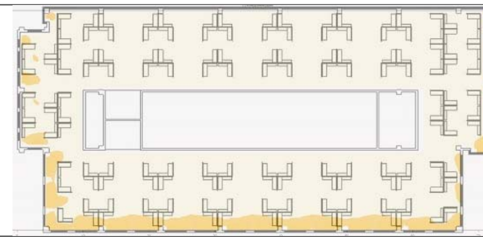
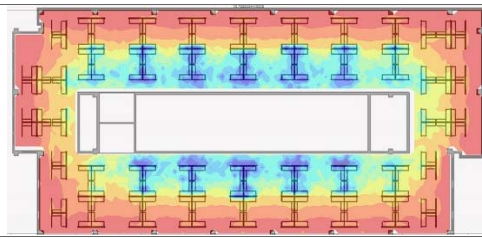
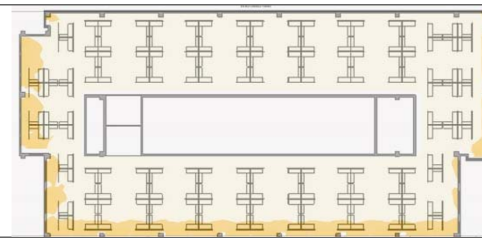
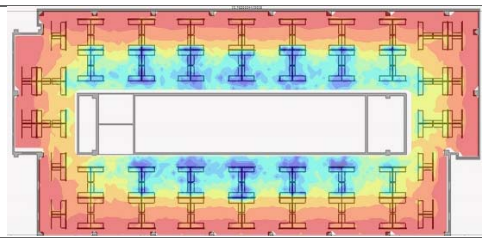
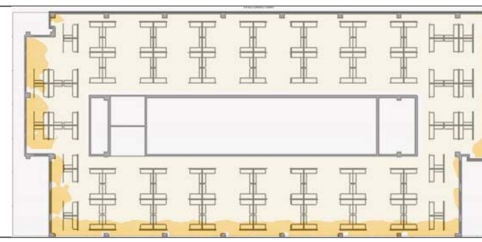
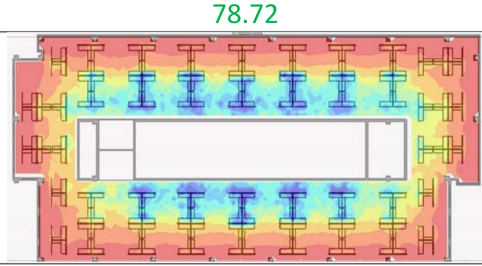
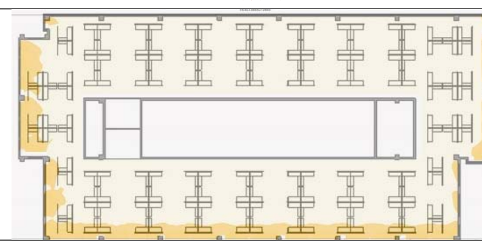
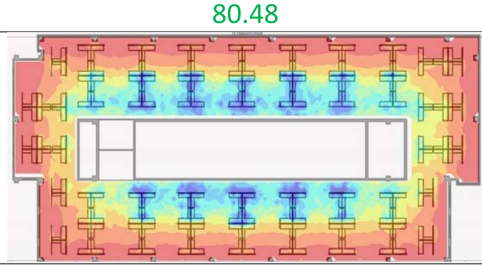
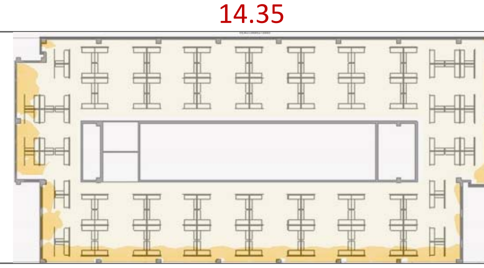
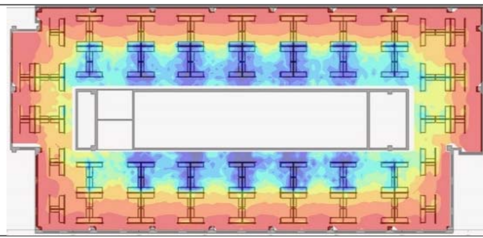
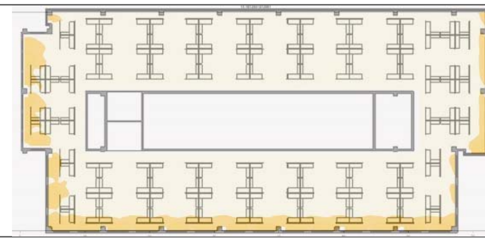
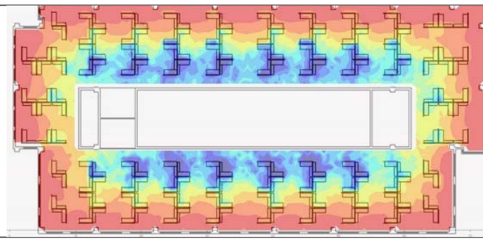
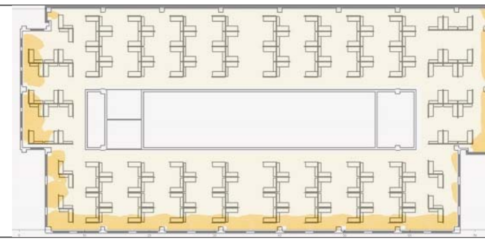
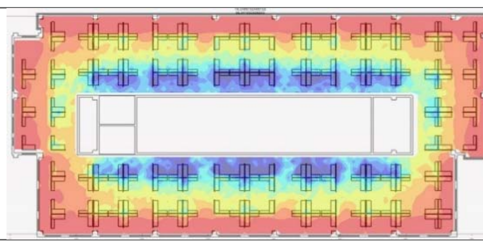
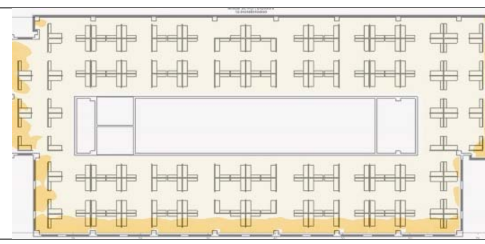
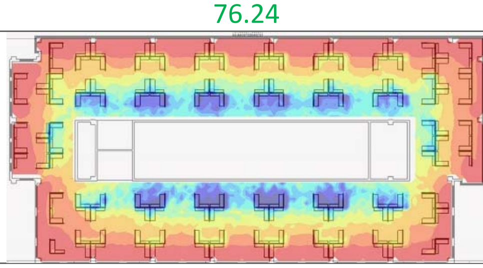
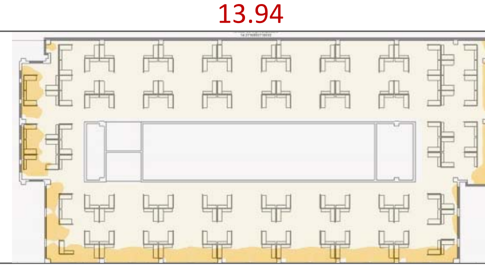
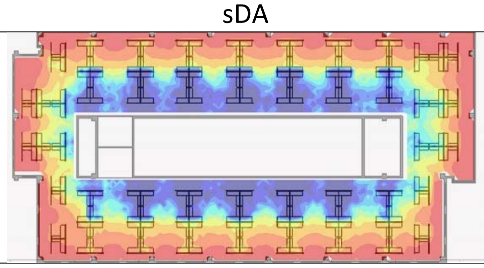
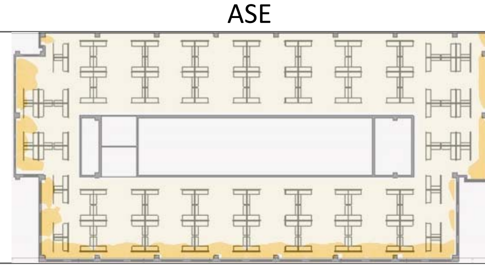
Per - SL		
	53.05	11.40

Figure 27. Simulation Plots - Translucent Partitions (20% LT)

Translucent Partitions (50% Light Transmittance)		
42”	sDA	ASE
Para - BL		
	77.25	14.53
Para - SL		
	78.72	14.74
Per - BL		
	80.48	14.35
Per - SL		
	83.98	14.57

48”	sDA	ASE
Para - BL		
	71.15	14.10
Para - SL		
	72.58	14.57
Per - BL		
	76.24	13.94
Per - SL		
	79.13	14.27

60”	sDA	ASE
Para - BL		
	64.61	13.41

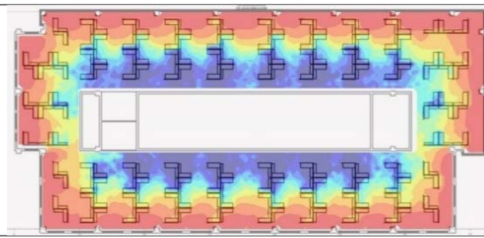
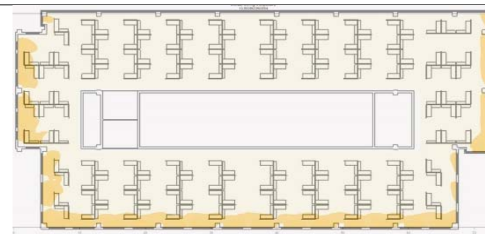
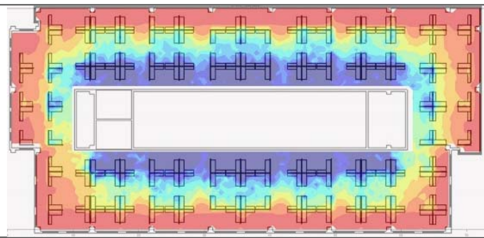
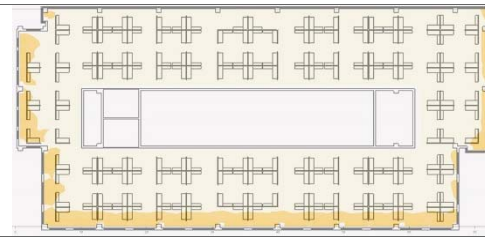
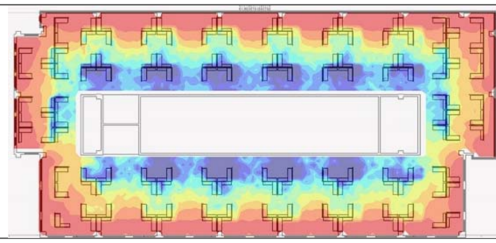
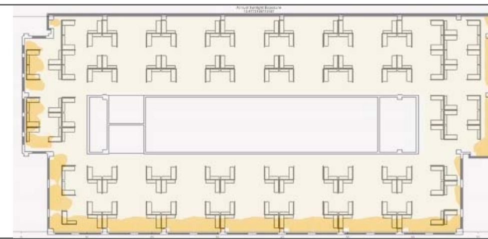
Para - SL		
	63.98	13.96
Per - BL		
	62.30	13.55
Per - SL		
	67.77	13.67

Figure 28. Simulation Plots - Translucent Partitions (50% LT)

Looking at sDA plots in Figures 27 and 28, implementing translucent materials instead of opaque materials brings more daylight into the study space. As it was expected, sDA and ASE values were reported higher in translucent partitions with 50% light transmittance in comparison to the 20% light transmittance in translucent partitions.

The plots illustrated in Figures 27 and 28 and the sDA and ASE values shown in Figure 31 reveal that in the translucent partitions, the highest amount of annual daylight sufficiency (sDA) belong to those partitions oriented perpendicular to windows based on spine layout (71.75% in average versus 68.2% total average). The lowest ASE values were recorded in those partitions oriented perpendicular to windows based on bridge layouts, yet the values are almost in the same range. Further zone-by-zone investigation on the daylighting impacts of translucent materials (Tables 11 and 12) reveals that sDA values on the north and south façades are relatively low (47.88% and 52.17% in average respectively) regardless of partition orientation and layout, while the sDA values are considerably high on the east and west façades (84.7% and 90.66% in average, respectively).

In translucent partitions (20% and 50% light transmittance), ASE values are always zero on the north façade since this façade never hits 1000 lux in 250 occupied hours. The ASE values recorded on the east side of the building are almost unresponsive to the partition height, orientation and layout. The ASE values on the west and south façades show more sensitivity and variation based upon different partition heights, orientations, and layouts. On the south façade, translucent partitions oriented parallel to the windows based upon bridge layouts blocks sunlight more efficiently than other alternatives (16.51% ASE in average versus 17.65% total ASE average).

Table 11. Simulation Results (sDA-ASE) - Translucent Partitions (20% LT)

Translucent (20% LT)	Para-BL 42"	Para-SL 42"	Per-BL 42"	Per-SL 42"	Para-BL 48"	Para-SL 48"	Per-BL 48"	Per-SL 48"	Para-BL 60"	Para-SL 60"	Per-BL 60"	Per-SL 60"
N	57.70	50.33	62.78	53.60	49.85	42.84	52.27	45.20	45.86	37.40	33.23	31.78
S	63.99	54.20	67.56	58.14	55.66	46.95	56.81	50.38	48.92	39.31	36.96	36.01
E	94.36	87.07	96.00	87.66	91.77	78.97	91.54	80.14	77.32	68.98	80.73	67.33
W	94.82	97.87	98.02	97.71	91.77	96.34	93.75	92.68	77.74	88.57	82.16	85.06
Total	74.32	72.37	71.35	77.10	63.98	61.73	63.96	69.36	48.99	55.22	57.35	53.05

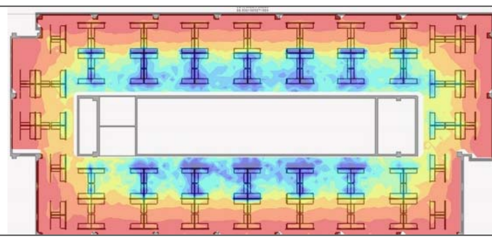
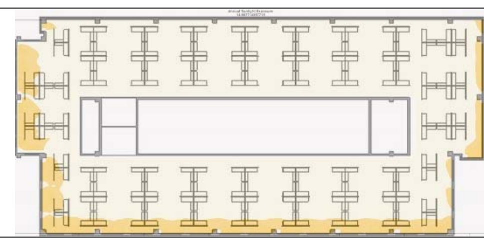
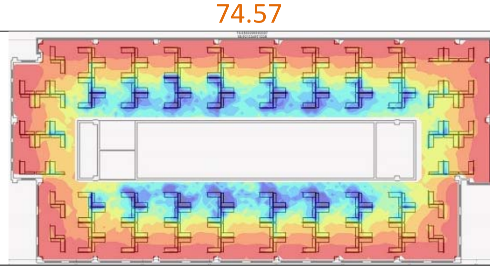
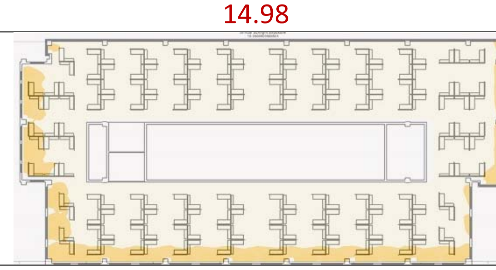
Translucent (20% LT)	Para-BL 42"	Para-SL 42"	Per-BL 42"	Per-SL 42"	Para-BL 48"	Para-SL 48"	Per-BL 48"	Per-SL 48"	Para-BL 60"	Para-SL 60"	Per-BL 60"	Per-SL 60"
N	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S	17.77	17.96	19.17	18.54	15.92	16.37	18.51	17.96	12.74	14.46	17.45	17.32
E	17.20	17.08	17.08	16.96	17.20	16.96	16.73	16.84	16.73	16.84	16.37	16.37
W	30.43	26.76	29.20	27.68	27.06	24.92	25.54	24.92	25.54	21.71	21.71	15.60
Total	13.30	13.51	12.89	13.88	12.61	12.85	12.18	13.26	11.81	11.87	10.58	11.40

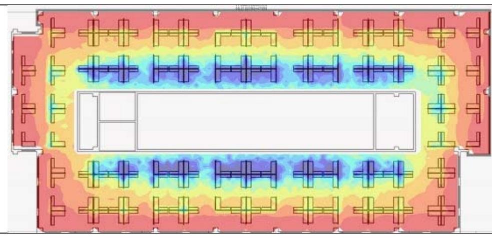
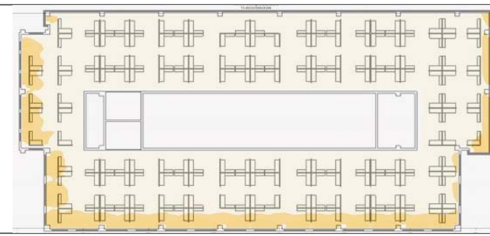
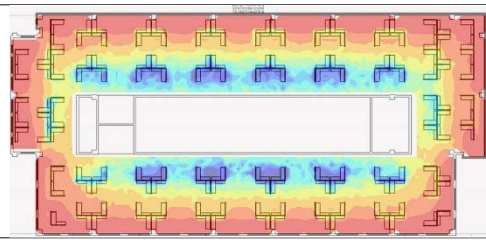
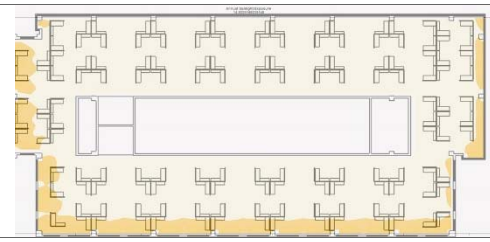
Table 12. Simulation Results (sDA-ASE) - Translucent Partitions (50% LT)

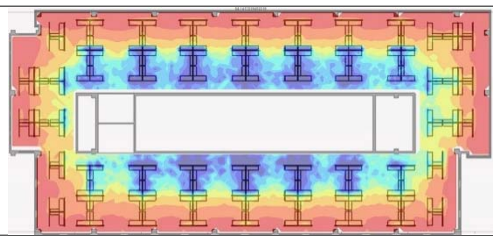
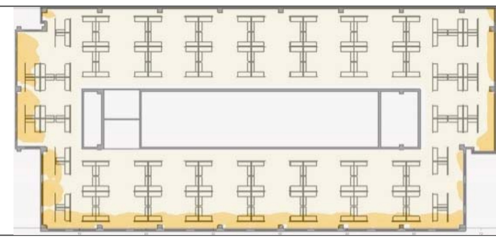
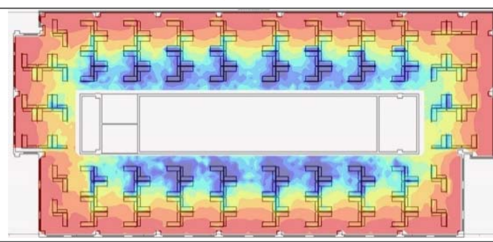
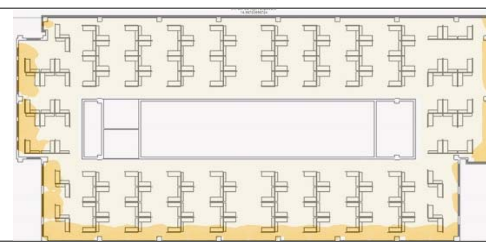
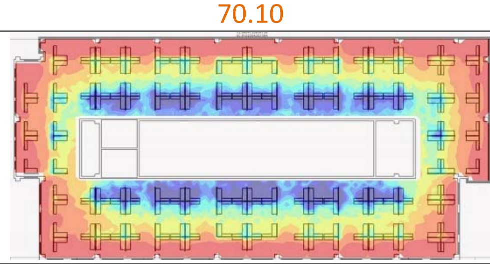
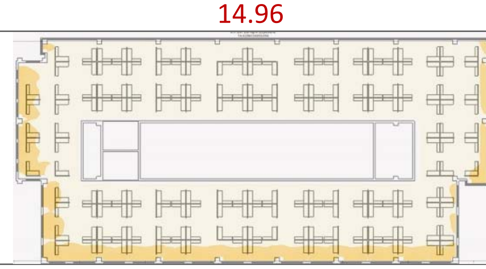
Translucent (50% LT)	Para-BL 42"	Para-SL 42"	Per-BL 42"	Per-SL 42"	Para-BL 48"	Para-SL 48"	Per-BL 48"	Per-SL 48"	Para-BL 60"	Para-SL 60"	Per-BL 60"	Per-SL 60"
N	52.51	53.41	57.64	59.19	49.01	49.18	48.40	54.14	46.22	42.66	33.35	40.73
S	58.46	58.72	60.43	64.44	53.69	51.97	51.34	59.03	48.73	46.06	39.25	45.17
E	92.24	93.07	92.60	92.71	87.31	87.66	87.66	86.49	74.38	77.79	79.32	79.67
W	99.09	99.85	99.85	99.85	98.32	99.54	99.70	99.85	95.73	96.34	96.49	94.66
Total	77.25	78.72	80.48	83.98	71.15	72.58	76.24	79.13	60.48	57.67	62.30	67.77

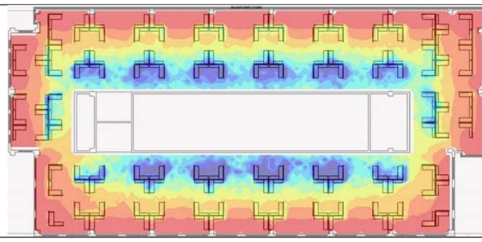
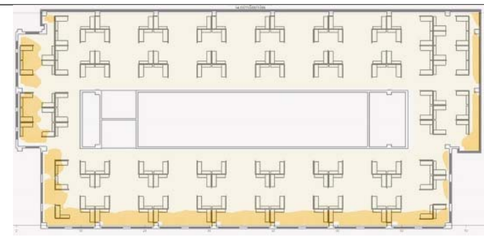
Translucent (50% LT)	Para-BL 42"	Para-SL 42"	Per-BL 42"	Per-SL 42"	Para-BL 48"	Para-SL 48"	Per-BL 48"	Per-SL 48"	Para-BL 60"	Para-SL 60"	Per-BL 60"	Per-SL 60"
N	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S	18.85	19.11	19.24	19.17	18.03	18.54	18.79	18.73	15.80	16.62	18.15	18.47
E	17.43	17.31	17.20	17.31	17.20	17.20	16.96	17.20	17.20	17.20	16.84	17.08
W	26.48	27.52	24.77	28.13	24.62	26.30	22.78	25.69	23.55	23.39	21.25	16.67
Total	14.53	14.74	14.35	14.57	14.10	14.57	13.94	14.27	13.41	13.96	13.55	13.67

Annual simulations were also run based upon transparent partitions in two different visual light transmittances (30% and 50%) and sDA and ASE results are plotted in Figures 29 and 30. Looking at sDA plots in Figures 29 and 30, using transparent materials causes more daylight to enter the space as opposed to opaque and translucent partitions. Similar to translucent partitions, sDA values are relatively higher in those transparent partitions oriented perpendicular to windows based on spine layouts (75.7% in average versus 72.88% total average). Comparing ASE values in transparent partitions with different orientations and layouts, the risk of excessive sunlight exposure is slightly lower in those partitions oriented perpendicular to windows based on bridge and spine layouts, yet the values are almost in the same range.

Transparent Partitions (30% Visible Light Transmission)		
42”	sDA	ASE
Para - BL		
	74.57	14.98
Para - SL		
	75.65	15.06

Per - BL		
	77.86	14.80
Per - SL		
	80.61	14.82

48”	sDA	ASE
Para- BL		
	68.26	14.78
Para - SL		
	70.10	14.96
Per - BL		
	72.56	14.63

Per - SL		
	75.32	14.55

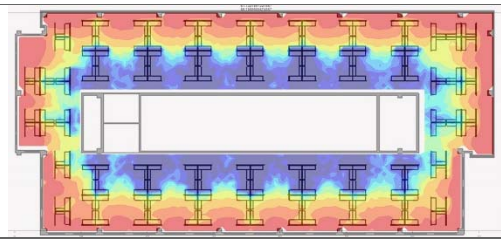
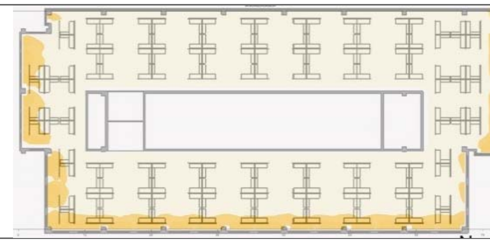
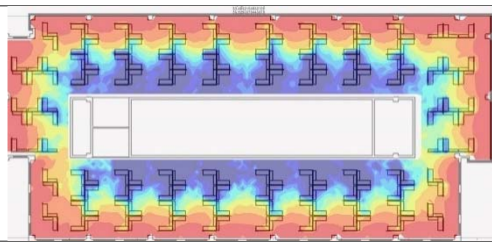
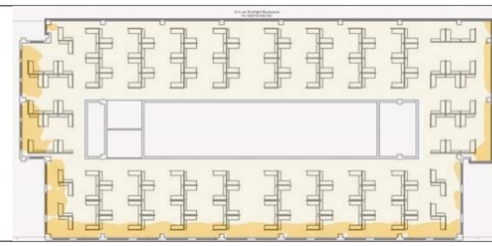
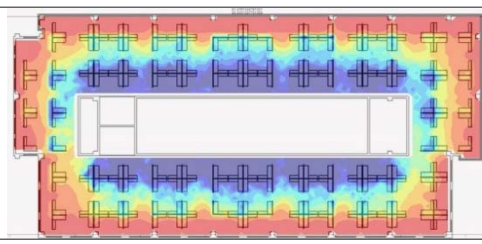
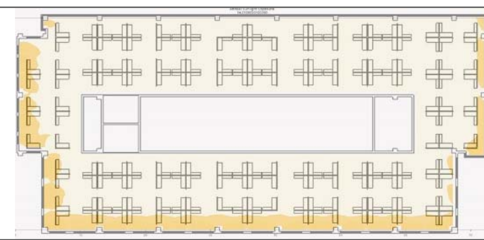
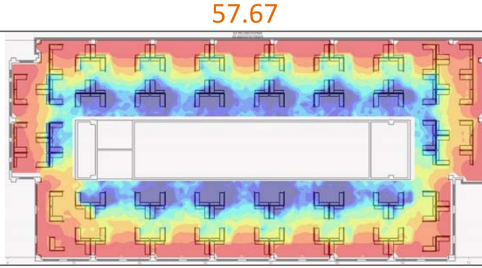
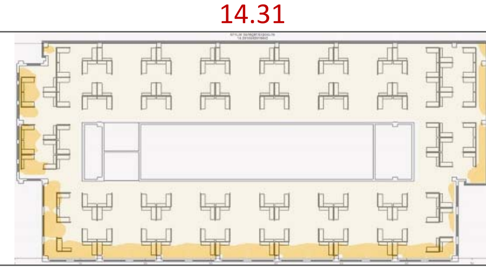
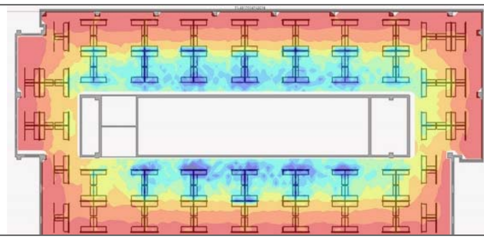
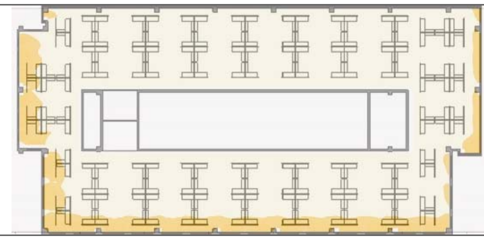
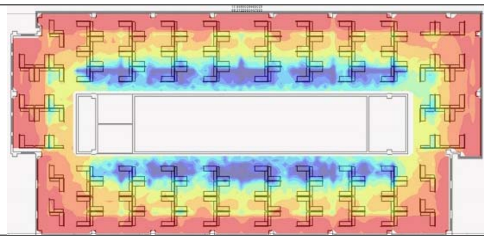
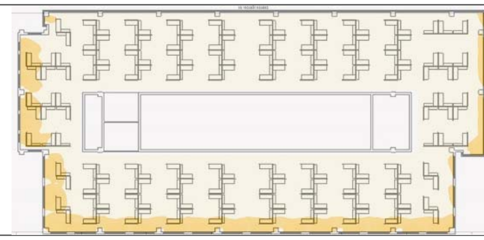
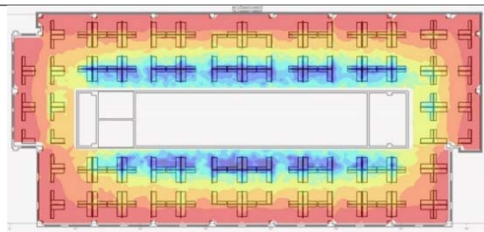
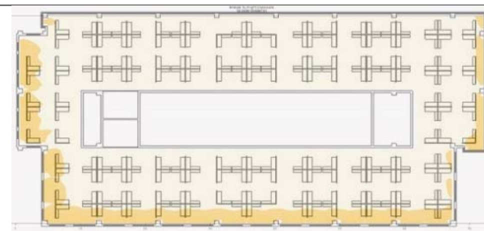
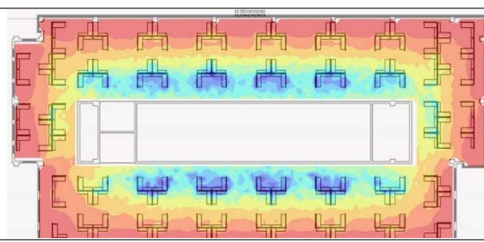
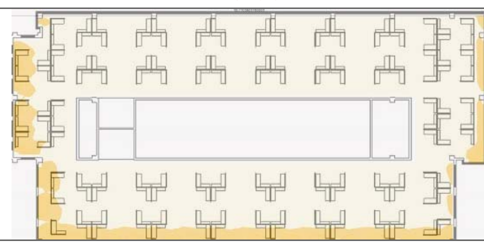
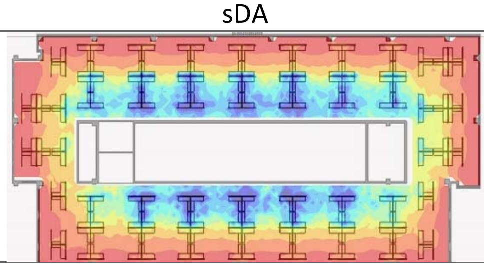
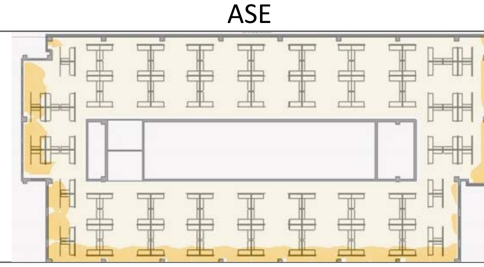
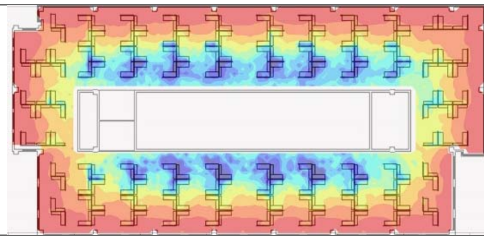
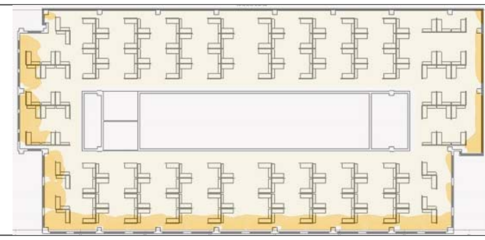
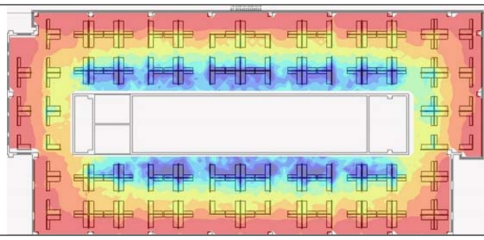
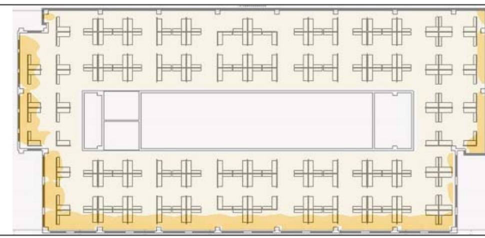
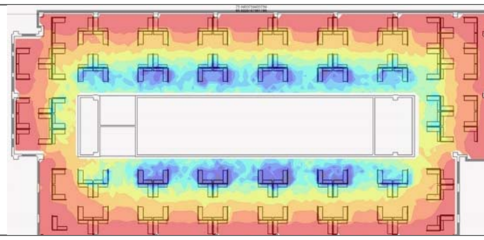
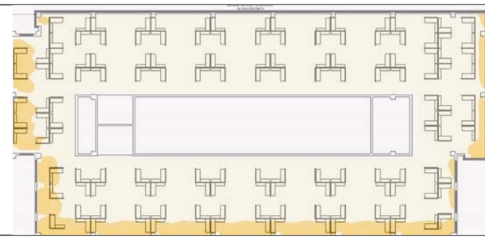
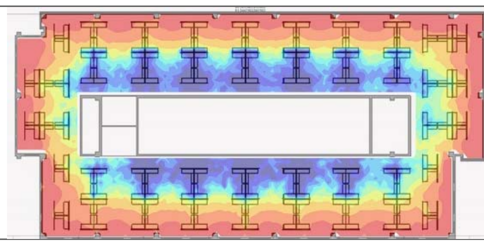
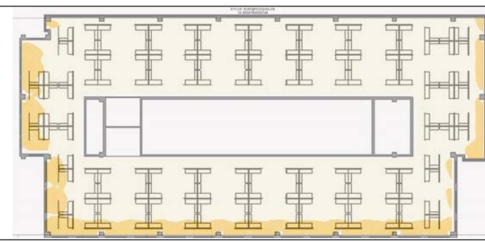
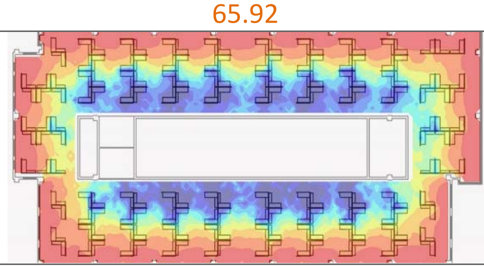
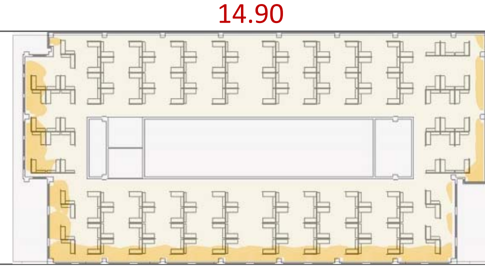
60”	sDA	ASE
Para-BL		
	61.73	14.43
Para-SL		
	60.48	14.74
Per - BL		
	57.67	14.31
Per - SL		
	63.96	14.29

Figure 29. Simulation Plots - Transparent Partitions (30% VLT)

Transparent Partitions (50% Visible Light Transmission)		
42”	sDA	ASE
Para - BL		
	78.54	15.15
Para - SL		
	77.86	15.19
Per - BL		
	80.34	15.06
Per - SL		
	83.25	15.11

48”	sDA	ASE
Para - BL		
	72.64	15.13

Para - SL		
	74.20	15.15
Per - BL		
	76.55	15.02
Per - SL		
	79.44	15.00
60”	sDA	ASE
Para - BL		
	65.92	14.90
Para - SL		
	66.64	15.04

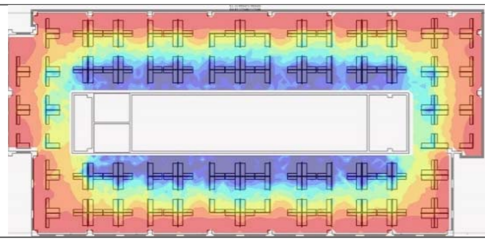
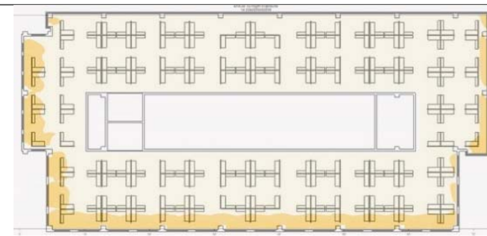
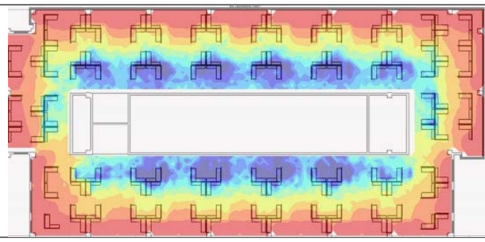
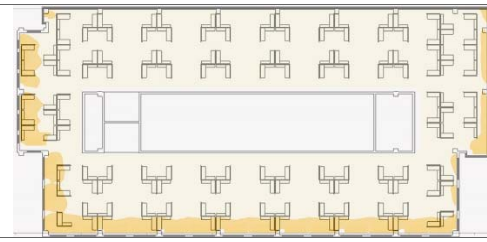
Per - BL		
	67.17	14.92
Per - SL		
	70.08	14.90

Figure 30. Simulation Plots - Transparent Partitions (50% VLT)

Likewise, the zone-by-zone investigation of daylighting impacts of transparent materials with 30% and 50% VLT was conducted and illustrated in Tables 13 and 14 respectively. Tables 13 and 14 show that sDA values on the north and south façades are relatively low (48.51% and 52.81% in average, respectively) regardless of partition orientation and layout, while the sDA values are considerably high on the east and west façades (84.4% and 97.99% in average, respectively). Moreover, the sDA values reported on the east and west are almost identical. In other words, the height, orientation, and layout of transparent partitions does not have considerable impact on daylight availability on the east and west zones of open plan office spaces.

Again, ASE values are zero on the north façade since this façade never hits 1000 lux in 250 occupied hours. As expected, the west and south façades have more sensitivity and variation to partition height, orientation, and layout. On the south façade, transparent partitions oriented parallel to the windows based upon bridge layouts reduce the risk of excessive sunlight exposure slightly more than other alternatives (18.47% ASE in average versus 19.05% total ASE average).

Table 13. Simulation Results (sDA-ASE) - Transparent Partitions (30% VLT)

Transparent (30% VLT)	Para-BL 42"	Para-SL 42"	Per-BL 42"	Per-SL 42"	Para-BL 48"	Para-SL 48"	Per-BL 48"	Per-SL 48"	Para-BL 60"	Para-SL 60"	Per-BL 60"	Per-SL 60"
N	50.33	52.15	55.47	55.89	47.43	46.22	44.41	51.12	43.81	39.70	31.48	36.13
S	56.11	55.85	58.21	62.34	51.72	50.19	47.90	57.25	45.36	43.70	35.50	42.43
E	89.54	89.78	89.89	89.54	81.79	83.68	84.37	83.55	70.39	75.09	74.15	74.03
W	98.17	99.54	99.85	99.85	96.49	98.48	99.54	98.48	92.68	94.66	94.05	90.24
Total	74.57	75.65	77.86	80.61	68.26	70.10	72.56	75.32	65.68	65.72	64.61	65.49

Transparent (30% VLT)	Para-BL 42"	Para-SL 42"	Per-BL 42"	Per-SL 42"	Para-BL 48"	Para-SL 48"	Per-BL 48"	Per-SL 48"	Para-BL 60"	Para-SL 60"	Per-BL 60"	Per-SL 60"
N	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S	19.17	19.43	19.55	19.55	18.47	18.92	19.49	19.43	16.62	17.52	19.24	18.98
E	17.43	17.43	17.31	17.31	17.31	17.08	17.20	17.20	17.31	17.08	17.08	17.08
W	26.91	27.98	26.15	28.59	24.92	26.45	23.39	26.76	24.01	25.23	22.17	22.48
Total	14.98	15.06	14.80	14.82	14.78	14.96	14.63	14.55	14.43	14.74	14.31	14.29

Table 14. Simulation Results (sDA-ASE) - Transparent Partitions (50% VLT)

Transparent (50% VLT)	Para-BL 42"	Para-SL 42"	Per-BL 42"	Per-SL 42"	Para-BL 48"	Para-SL 48"	Per-BL 48"	Per-SL 48"	Para-BL 60"	Para-SL 60"	Per-BL 60"	Per-SL 60"
N	52.63	54.98	58.19	58.91	49.18	50.57	53.17	54.98	46.71	43.87	40.97	45.97
S	58.40	59.16	61.20	63.49	55.09	55.22	55.98	60.62	48.98	47.14	44.15	51.46
E	92.71	93.07	92.83	92.24	87.90	88.13	87.66	88.25	77.32	79.20	80.73	79.91
W	99.24	99.85	99.85	99.85	98.63	99.70	99.85	99.70	96.80	98.78	99.09	98.48
Total	78.54	77.86	80.34	83.25	72.64	74.20	76.55	79.44	65.92	66.64	67.17	70.08

Transparent (50% VLT)	Para-BL 42"	Para-SL 42"	Per-BL 42"	Per-SL 42"	Para-BL 48"	Para-SL 48"	Per-BL 48"	Per-SL 48"	Para-BL 60"	Para-SL 60"	Per-BL 60"	Per-SL 60"
N	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S	19.30	19.62	19.62	19.62	19.17	19.30	19.55	19.49	18.09	18.47	19.49	19.30
E	17.43	17.43	17.31	17.31	17.43	17.43	17.31	17.31	17.31	17.31	17.20	17.20
W	27.98	28.90	27.22	28.59	26.19	28.13	25.84	27.52	25.54	27.22	24.46	24.31
Total	15.15	15.19	15.06	15.11	15.13	15.15	15.02	15.00	14.90	15.04	14.92	14.90

Overall, the results shown above reveal that partition material, height, orientation, and layout have robust impacts on the amount of daylight received and occupants' visual comfort. Figures 31 and 32 summarize and compare annual daylighting simulation results (sDA and ASE respectively) of 60 scenarios of partition design. Each Figure is divided into five sections according to the partition material. In Figure 31, a dark green, medium green, and light green line represent partition height alternatives (42", 48", and 60" heights, respectively). The lowest sDA value in this study space belongs to the opaque partitions (20% Reflection) with 60" height in perpendicular partition orientation to windows based on spine layouts (46.6%), while the highest value is reported in transparent partitions (50% VLT) with 42" height in perpendicular partition orientation to windows based on spine layouts (84%).

In Figure 32 a dark orange, medium orange, and light orange line represent partition alternatives (42", 48", and 60" heights, respectively). Based on the 60 simulated plots, the lowest ASE value is recorded in just two partition designs: opaque partitions (Reflection 20%) with 60" height parallel to windows based on bridge layouts and translucent partitions (20% Visible Light Transmission) with 60" height perpendicular to windows based on bridge layouts (10.83% and 10.58%). They are close to the 10% ASE criteria adopted in LEED V4. Although it is worth noting that several studies reveal that the 10% ASE criteria appears to be too restrictive and may result in many good daylighting designs failing to meet the criteria (Nezamdoost, 2015; Nezamdoost & Van Den Wymelenberg, 2016; Reinhart, 2015).

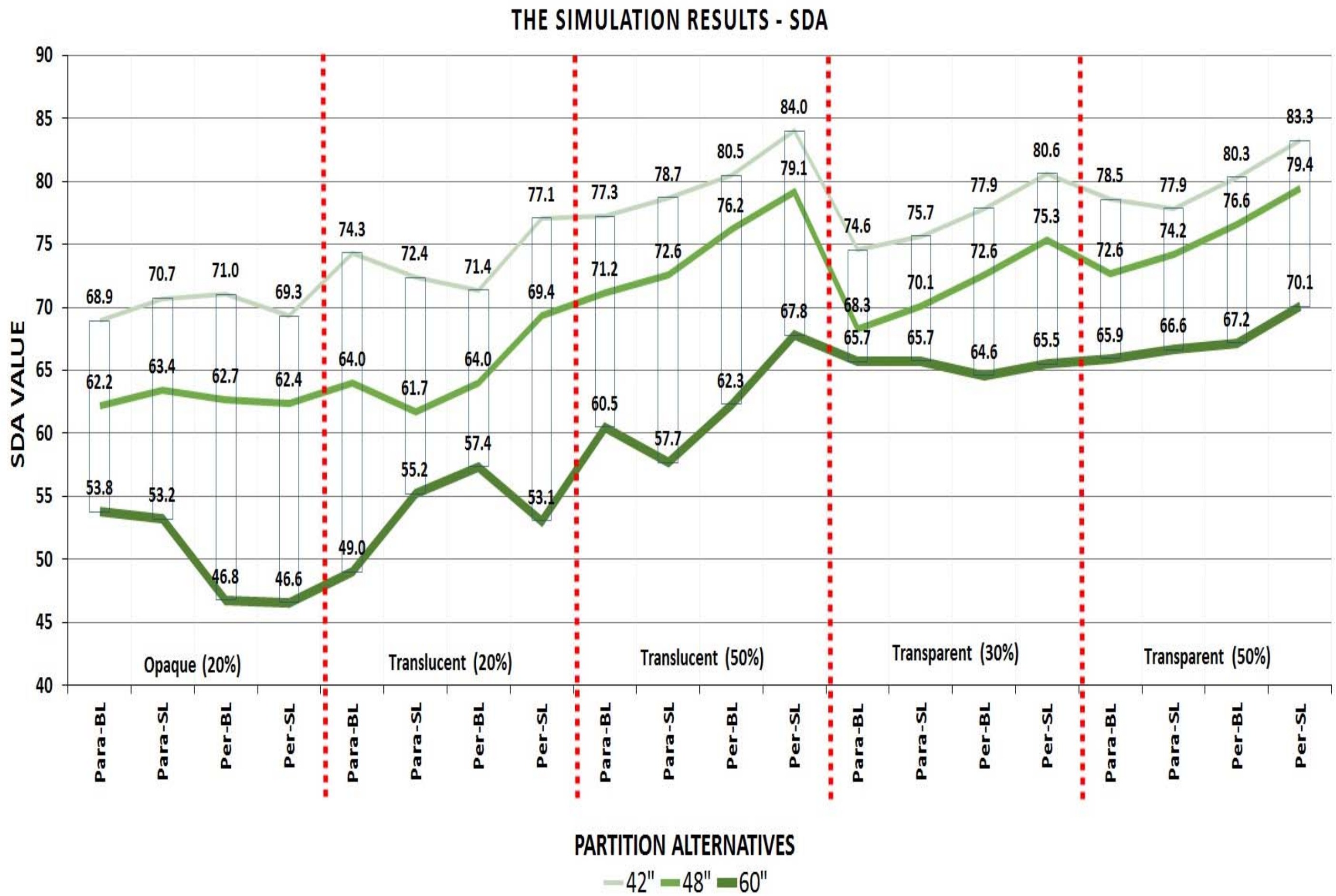
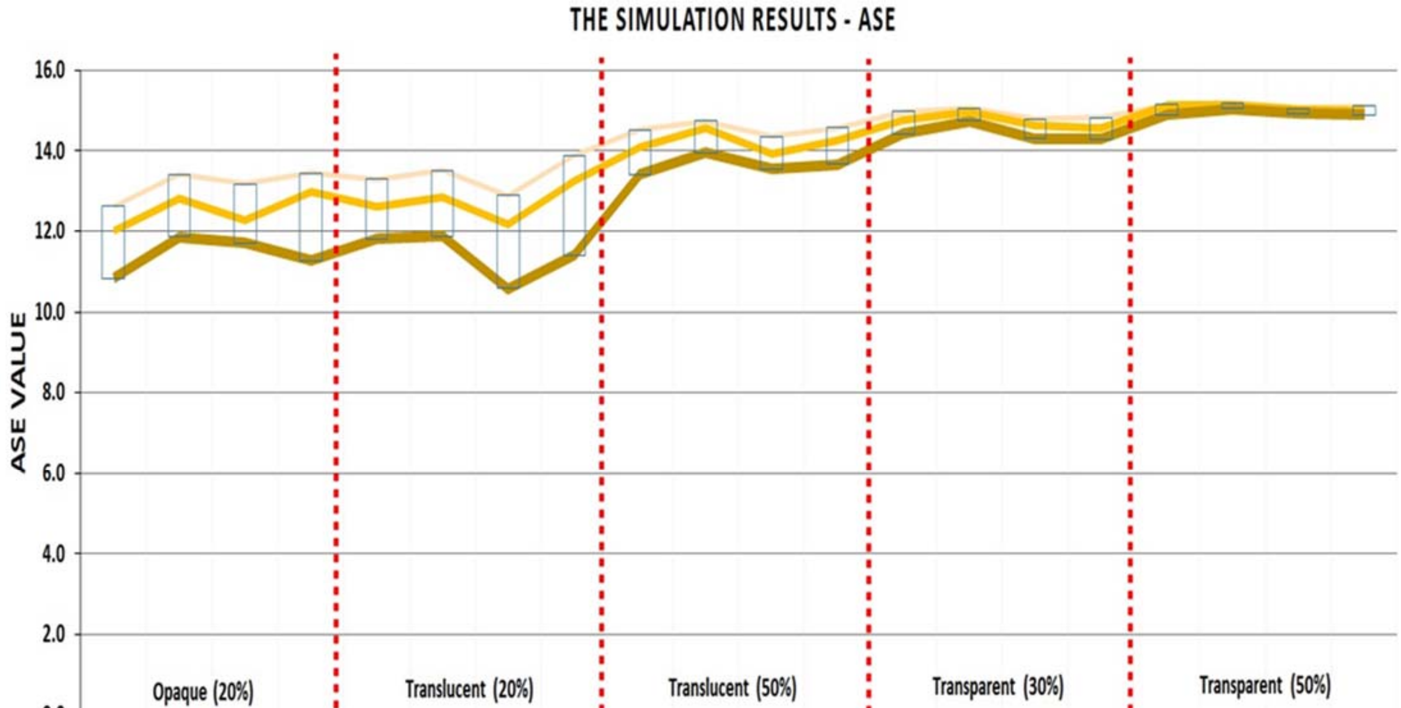


Figure 31. Comparing sDA Results of Partition Design on Each Side of Building



	Opaque (20%)				Translucent (20%)				Translucent (50%)				Transparent (30%)				Transparent (50%)			
	Para-BL	Para-SL	Per-BL	Per-SL	Para-BL	Para-SL	Per-BL	Per-SL	Para-BL	Para-SL	Per-BL	Per-SL	Para-BL	Para-SL	Per-BL	Per-SL	Para-BL	Para-SL	Per-BL	Per-SL
42"	12.6	13.4	13.2	13.5	13.3	13.5	12.9	13.9	14.5	14.7	14.4	14.6	15.0	15.1	14.8	14.8	15.2	15.2	15.1	15.1
48"	12.01	12.81	12.3	13	12.6	12.9	12.2	13.3	14.1	14.57	13.94	14.27	14.8	15.0	14.6	14.6	15.1	15.2	15.0	15.0
60"	10.83	11.85	11.71	11.26	11.8	11.9	10.6	11.4	13.41	13.96	13.55	13.67	14.4	14.7	14.3	14.3	14.9	15.0	14.9	14.9

PARTITION ALTERNATIVES

Figure 32. Comparing ASE Results of Partition Design on Each Side of Building

CHAPTER V

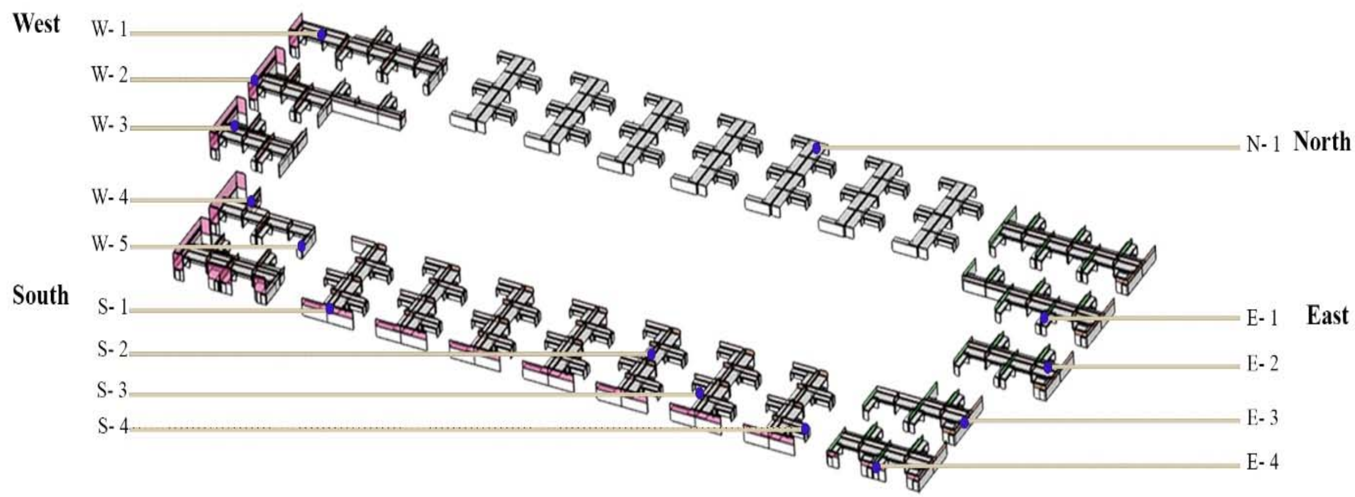
DISCUSSION

This research plan was conducted to determine which partition height, material, orientation, and workstation layout in side-lit open office spaces provides the maximum amount of daylight (high sDA) with the minimum risk of excessive sunlight exposure (low ASE) in order to provide insight to the commercial building design community about the application of daylight in the development of future generations of office furniture. The results reveal that the workstation layout considerably impacts annual daylight performance and occupants' visual comfort. Furthermore, depending which, partition material, height, and orientation is implemented, the results differ dramatically. It is reported that opaque partitions considerably decreased the number of hours that the floor area achieves 300 lux during 50% of annual occupied hours. Instead, translucent partitions let more daylight come into the study space. As expected, sDA and ASE values were reported higher in translucent partitions with 50% light transmittance in comparison to the 20% light transmittance of translucent partitions. Transparent partitions provided more daylight than the other partition materials, yet increased the risk of excessive daylight and glare. Workstation partitions with 42" height minimally influenced the amount of incoming daylight and could be implemented in areas where there is good view quality as well as low probability of sun penetration.

On the contrary, higher partitions, 48” or greater, provide privacy and a sense of enclosure yet considerably block the daylight. Spine workstation layouts show better performance in providing privacy, storage areas, and not preventing diffuse daylight due to the position and shape of partitions. Looking at sDA and ASE plots, a similar workstation partition design cannot be considered for four orientations of the building; an appropriate partition should be designed and arranged based on the unique characteristics of each building orientation in order to adequately address the dynamic change of daylight during the course of the day and year.

In the north façade, the ASE values are always zero regardless of partition height and layout since this façade never hits 1000 lux in 250 occupied hours. Hence, open desk workstations with at least transparent and low partition heights are recommended. sDA values on the south façade are relatively low and the ASE values show more sensitivity to partition height, material, and layout. It is recommended to provide opaque or translucent partitions with at least 48” height for the perimeter zone and to use transparent partitions in the core. In the east façade, high sDA values were recorded. ASE values are almost in the same range (17.07) and are unresponsive to the partition height, orientation, and layout. Therefore, transparent or translucent partitions with minimum heights would be adequate to provide visually comfortable conditions for occupants; however, interior blinds or other shading devices are necessary to block the excessive daylight and sky brightness during morning hours. Relatively high sDA and ASE values were reported on the west façade causing excessive solar heat gain and intense glare issues during afternoon and evening hours. In order to reduce the amount of harsh sun penetration on occupants' desks, opaque or translucent partitions with 60" height in the perimeter zone are required.

The height, orientations, and materiality of partitions (surface reflection and light transmittance) influence the amount of transferred daylight from the windows and lighting conditions of a space. However, daylit buildings are rarely studied while in use or examined in terms of the impact of interior design strategies on the level of daylight availability. Further studies are required to diagnose the specific daylighting design strategies in order to improve the current design pattern guides. From the findings above and daylight performance analysis of 60 different workstation partitions through simulation, one alternative was selected and developed based on façade orientation, window to wall ratio, number of employees, and space depth. The elaborated design of the recommended alternative is provided on Figures 33 and 34.



W-1	42" Height - Transparent 30						
W-2	60" Height - Translucent 20	S-1	48" Height - Translucent 20	E-1	42" Height - Transparent 50	N-1	Desks Without Partitions - Opaque
W-3	48" Height - Translucent 50	S-2	42" Height - Transparent 30	E-2	42" Height - Transparent 30		
W-4	48" Height - Transparent 30	S-3	42" Height - Translucent 50	E-3	42" Height - Translucent 50		
W-5	42" Height - Translucent 50	S-4	48" Height - Transparent 30	E-4	42" Height - Translucent 20		

Figure 33. Details of Recommended Alternative

Figure 34. The Stair-Shape of Partitions.
Image Credit- Author

The simulation results of 60 alternatives revealed that those partitions oriented perpendicular to windows based on spine layout minimally decreased the amount of incoming diffuse daylight without glare during the course of the year (high sDA, low ASE). As shown in Figure 35, the amount of spatial Daylight Autonomy (sDA) in the recommended alternative peaks at 80.30% and the Annual Sunlight Exposure (ASE) metric is lowered to 9.91%.

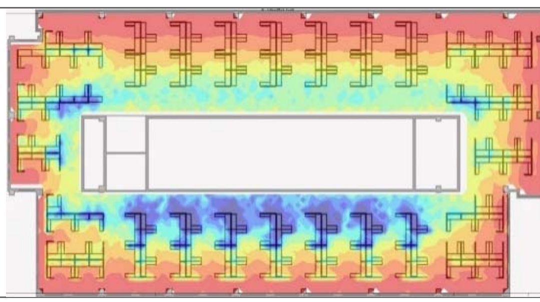
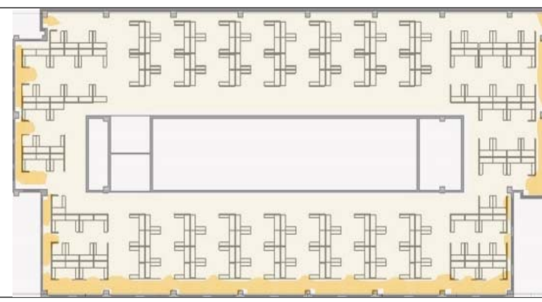
sDA	**ASE**
	
80.30	9.91

Figure 35. Simulation Plots – Recommended Partition Design

The recommended partition design reaches 3 points of LEED V4 daylight credit, since annual computer simulations show that sDA value exceeds 75% of preferred criteria and no more than 10% of analysis points in a space exceeds 1000 lux of direct sunlight for 250 hours as measured from 8:00 AM-6:00 PM. The recommended partition design has its own merits and shortcomings. It is established based on zone-by-zone daylight investigation to provide appropriate design for each façade orientation and address all sunlight and daylight variations in the course of the day and year. In the south and west facades, workstation partitions cannot solely lower the risk of daylight excessiveness, sun penetration, and solar heat gain in the perimeter zone. Therefore, interior and exterior shading devices should be implemented to maintain occupants' visual comfort.

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CHAPTER VI

CONCLUSION

The study conducted in this thesis is intended to provide a daylighting simulation analysis between a range of different items that can be used to assess and compare the performance of workstation partitions, with the goal of delivering maximum daylight in the course of the year. In order to properly assess the impacts of workstation partitions on the amount of transferred daylight from windows in to the space, the operation of 60 alternatives of partitions were examined (three different partition heights in five materials with two orientations to the windows based on workstation layouts) in four building orientations (north, south, east and west) through annual climate-based daylighting simulations. Workstation partitions show considerable impact on annual daylight performance and should be included in building daylighting simulation.

Although the previous studies believe that partitions are designed in open plan office spaces to provide privacy for employees, nobody can ignore the robust role of partition layouts in the better distribution of daylight into the space and providing a visually comfortable working environment. This study tries to raise the awareness and attention of manufacturers and designers regarding this issue as well as provide them insight to identify the items that highly impact the overall performance of workstation partitions in maximizing diffuse daylight and minimizing glare and visual discomfort.

With the implementation of the simulation results and literature reviewed herein, a workstation partition is proposed as a new model for open plan office spaces. The design preference regarding the heights, materials, orientations, and layouts have provided valuable guidance on design decisions. The following describes the proposed workstation partition:

A. In the northern façade which has no direct sunlight at any point in the day and no visual discomfort, open office spaces or partitions set at the lowest height to create privacy is recommended.

B. In the southern façade, in general, the less considerable discrepancy in ASE values (daylight excessiveness) can be caused by altering partitions, while stair-shape 48” translucent partitions increase acoustics and privacy while maintaining brightness.

C. In the eastern façade, as in southern façade, partitions have less considerable discrepancy in ASE values, hence 42” translucent partitions are required.

D. In the western façade, partitions have the most effect on daylight excessiveness due to excessive solar heat gain and intense glare issues, especially with lower altitude sun angles throughout the year in the late afternoon and evening. Therefore, stair-shape partitions from 60” to 42” height, which increase both visual and acoustic privacy, is suggested.

Future Research

Specific research gaps that should be investigated include the following:

- The proposed workstation partition design in this study should be considered as a hypothesis that requires validation in real open office spaces.
- Large-scale general human factor research into the effects of partition design and workstation layout on daylight sufficiency and visual comfort in real world settings could be examined through subjective qualitative questionnaires and objective measurements of illuminance and luminance.
- This study is conducted based upon two illuminance-based metrics on the horizontal task level; in order to accurately simulate the human perception of daylight and visual comfort we need to provide luminance-based metrics. We need to examine two luminance-based metrics.
- This research focused only on impacts of partition design on annual daylighting performance and did not explicitly review the substantial effects of exterior and interior shading devices on maintaining visual comfort in office spaces. Further research is needed to examine that combination and answer these questions:
    - Is there a relationship between view quality, blind occlusion, and partition height?
    - Do open-plan offices with external shading devices need lower partition height (due to less sun penetration)?
    - Do buildings with higher partitions generally have lower blind occlusion?

This study presents a comparison of 60 candidates of workstation partition design for one open office building in Raleigh, NC. Although these results can be reasonably extended to other regularly occupied work spaces with similar spatial configurations in order to achieve more generalizable results, additional evaluations of the impact within multiple climate zones, building shapes, and daylighting designs is warranted.

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APPENDIX A

STUDIO IAR 502

Design Projects- The Collaborative, Flexible, Innovative, and Sustainable Workplace

Introduction

The Grey Group has recently acquired a Raleigh-based advertising agency, and plans to build upon this foundation to create a new office to join its worldwide network, combining employees of the acquired agency with transplants from the New York and San Francisco offices. Two floors of Red Hat Tower (levels 9 and 10) in downtown Raleigh have been chosen as the site for this project. The two floors combined provide approximately 45,000 square feet of usable space. Approximately 37,000 square feet will be used for the office of Grey Raleigh, while the remaining 8,000, located on the southwest corner of the 10th floor, will be set aside as future growth space to be subleased until needed. This workplace will accommodate a fully-functioning advertising agency including creative teams, account managers, leadership personnel, and support staff. In all, Grey plans to move 149 employees into the new facility upon move-in.

Concept

My planning and design follow Grey's key values: collaboration, flexibility, innovation, and sustainability. As Grey holds these values as guiding principles, I will let them serve as a guide for my design. To employ these characteristics, the intent of this design is to take advantage of the interactive and innovative architecture, bringing in natural light and utilizing a combination of natural elements and colors.

Critical Design Solutions Required in the New Space Are:

- BRAND COHESION. This will be one of several hundred Grey Group offices worldwide. Thus, reflecting the company culture is essential, especially in spaces used by clients.
- COLLABORATION. The nature of the advertising/marketing industry requires frequent collaboration among teams. The new space must support this type of work.
- OPEN OFFICE. Grey has switched to an open office model in the last few years to further collaboration and engagement. This has become an integral part of the company culture.
- HISTORY. Grey was founded nearly 100 years ago, and the company celebrates its storied history. This should be reflected in the design.
- FLEXIBILITY. The marketing industry is fast-paced and constantly changing. Grey's new space must be able to adapt to the evolving needs of the agency.
- SUSTAINABILITY. Grey's worldwide headquarters is certified LEED Gold, so the design will need to reflect the company's commitment to sustainability.

Table 15. Occupant Requirements

	Occupant Requirements
Social	Communication, Interaction, Collaboration
Occupational	Desk, Chair, Cabinets, Tables, Pens, Paper, Markers
Technological	Computer, Keyboard, Telephone, Collaborative, Printer, Copier, Modeling Lab, Photography Lab, Intercom, Security System, Fire Alarms, Sprinkler Systems, Signage, Elevators
Psychological	Stimulating Work, Stimulating Interior Spaces, Intellectual Work, Safe Environment, Trust Leadership, Purposeful Work, Fair Rate of Pay Meditation Area, Privacy When Needed
Biological	Water, Restrooms, Breakroom, Good Lighting, Thermal Comfort, Fresh Air
Physiological	Ergonomic Chairs, Variety of Chair Types and Locations, Standing Desks, Collaborative Space That is Organized for Idea Generation with Whiteboards, and Other Essentials
Privacy	Mothers Room, Meditation Room, Conference Rooms, Meeting Areas, Restrooms
Creativity	Comfortable Leadership Allowing Freedom of Expression, Art Materials in Many Mediums, Equipment for Idea Production, Music, Art, Beautiful Views, Inspirational Work
Organizational	Human Resources, Wayfinding, Reserving Space, Scheduling
Recreational	Games, Shared Experiences

Programming

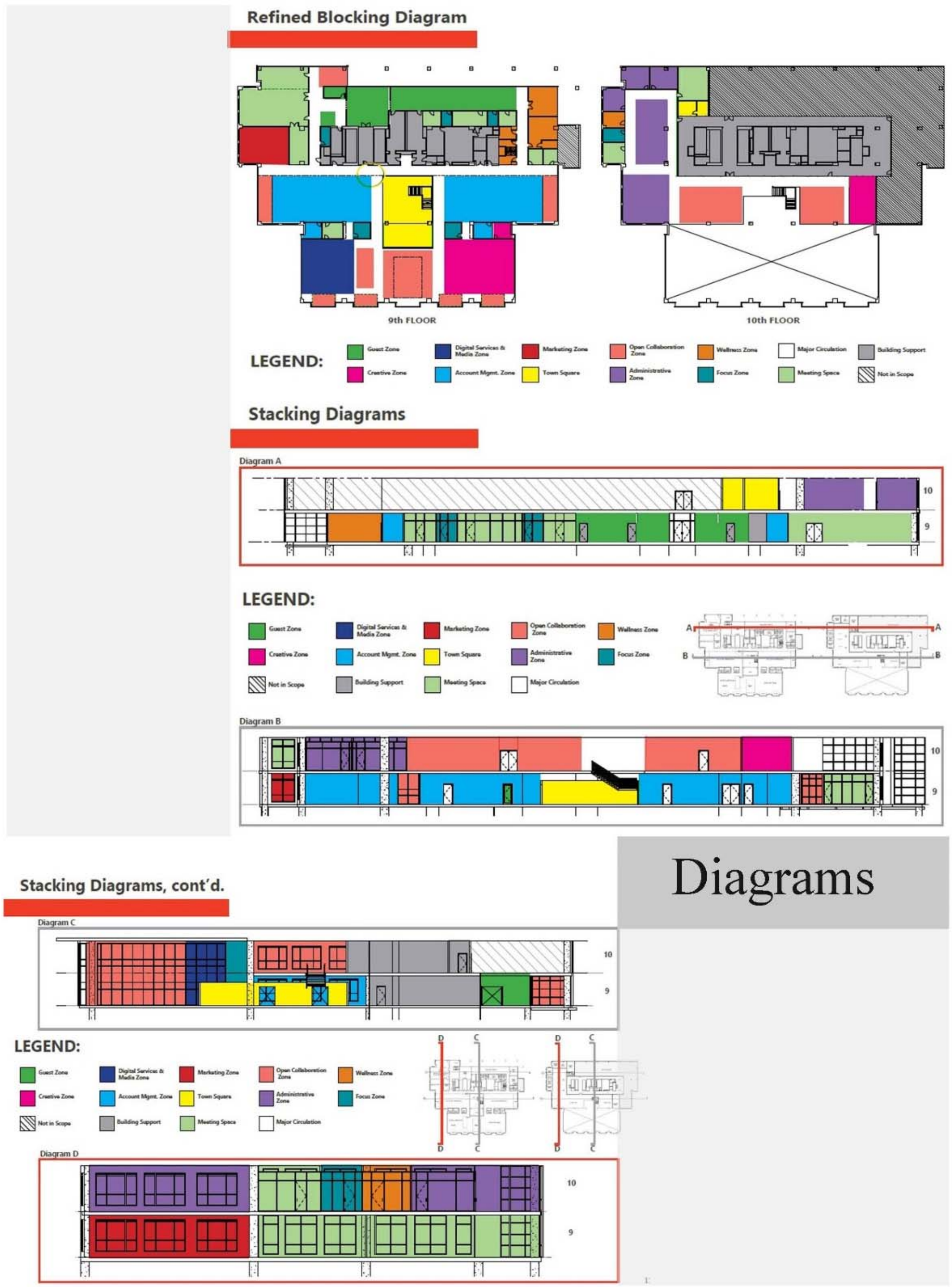


Figure 36. Programming

Special Requirement

GREY Raleigh

Space Requirements for Administration	Quantity	Dimensions	Subtotal Square Ft.	
PRIVATE OFFICE SPACE				
President, Raleigh	1	18' x 20'	360	Private
Chief Creative Officer, Raleigh	1	18' x 10'	180	Private
Human Resources Director	1	12' x 10'	120	Private
Managing Director	2	12' x 10'	240	Private
WORKSTATIONS/OPEN OFFICE				
Human Resources Staff	4	6' x 8'	192	Private
Legal	2	8' x 8'	128	Private
Accounting / Finance	6	6' x 8'	192	Semi-Private
Account Management Team	41	8' x 8'	2,624	Semi-Private
Growth/Drop-In - Acct. Mgmt.	4	8' x 8'	512	
Administrative Staff	5	6' x 8'	240	
Interns	4	6' x 6'	144	
Creative Teams	33	7' x 6'	1,386	Semi-Private
Growth/Drop-In - Creative	2	7' x 6'	96	
Public Relations	5	8' x 8'	320	
Technology Team (IT)	3	6' x 8'	144	
Receptionist	1	8' x 8'	64	
Marketing	10	8' x 8'	640	Shared
Media	12	6' x 8'	576	
Production	5	6' x 4'	120	
Research	3	6' x 6'	108	
Digital Services	13	6' x 6'	468	
Talent Coordination	2	6' x 6'	72	
Drop-In/Hotelling Stations	6	5' x 4'	120	
Enclave	10	8' x 8'	640	
PUBLIC / GUEST				
Lobby / Reception Area	1	25' x 25'	500	Public
Guest Restroom	1	8' x 8'	64	Public
MEETING				
Small Meeting Space (seats 4-6)	9	12' x 20'	2160	Shared
Collaborative Flex Space	1	30' X 20'	600	
Large Conference Space (seats 100)	1	70' x 50'	3500	Shared
Library (Knowledge Center)	1	30' X 20'	600	
Meditation Space / Mother's Room	2	10' x 10'	200	Private
Dedicated Project Room	3	10' x 12'	360	
Medium Conference Space (seats 10-15)	3	30' X 20'	1800	Shared

GREY Raleigh

Space Requirements for Administration	Quantity	Dimensions	Subtotal Square Ft.	
OFFICE SUPPORT				
Copy/Print	3	10' x 10'	300	Shared
Break Room + Kitchen	1	30' x 20'	600	Shared
Secure Long Term File Storage	1	10' x 15'	600	Secure
Work Room	1	12' x 10'	120	Shared
Production and Modeling	2	20' x 20'	800	Shared
Fitness Center	1	20' x 20'	400	Shared
Recreation Space	1	12' x 20'	240	Shared
Modeling Lab (Distillery)	1	12' x 20'	240	Shared
BUILDING SUPPORT				
Lockers	1	5' x 20'	100	Shared
Shower	2	4' x 4'	32	Shared
Storage-Small	4	6' x 6'	144	Shared
Storage-Large	1	10' x 12'	120	Shared
			23166	
TOTAL			23166	
CIRCULATION X 1.25%			x 1.25	
MEP X 1.25%			28,958	

Figure 37. Special Requirement

Schematic Design

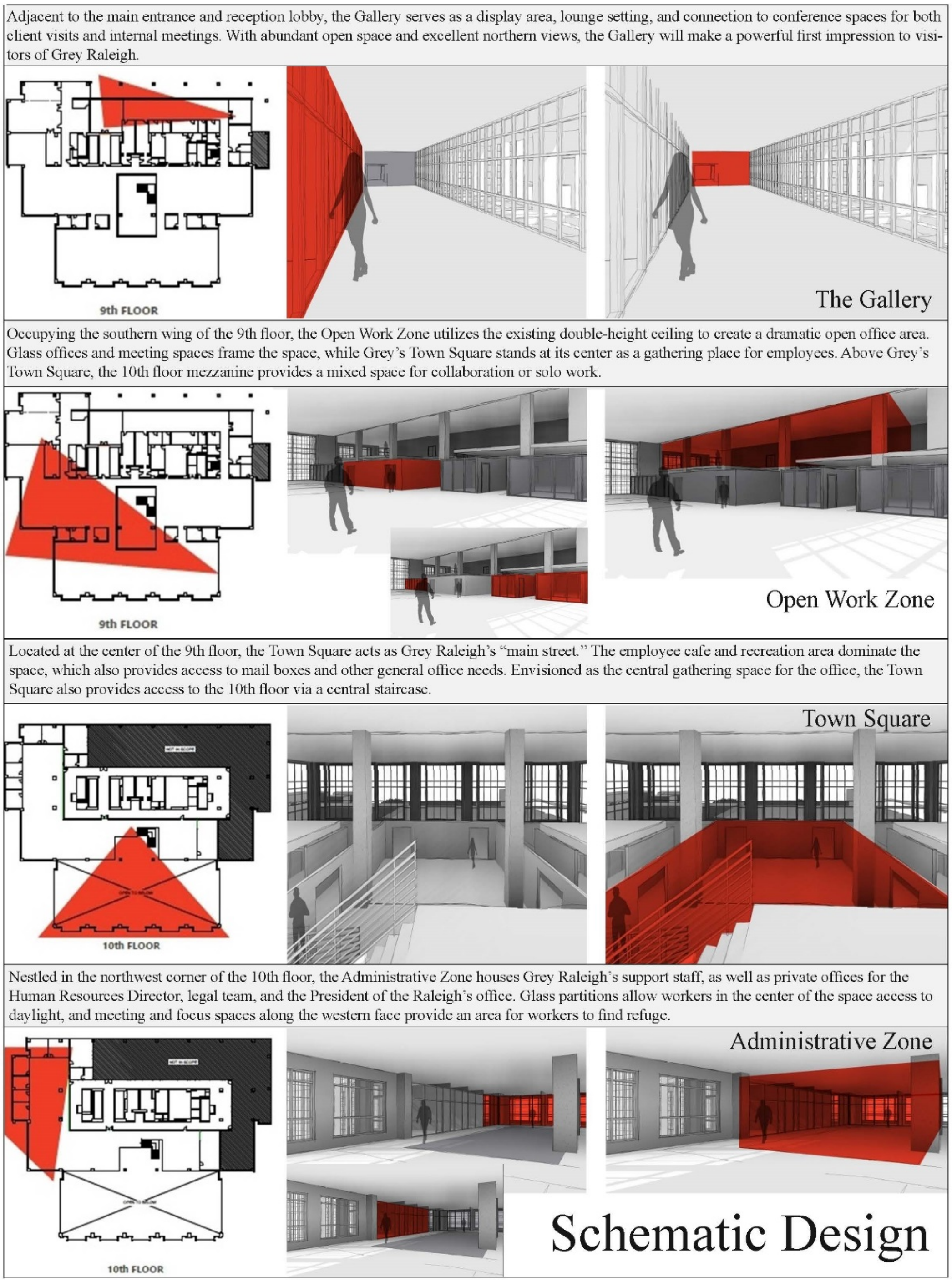


Figure 38. Schematic Design

Design Proposal

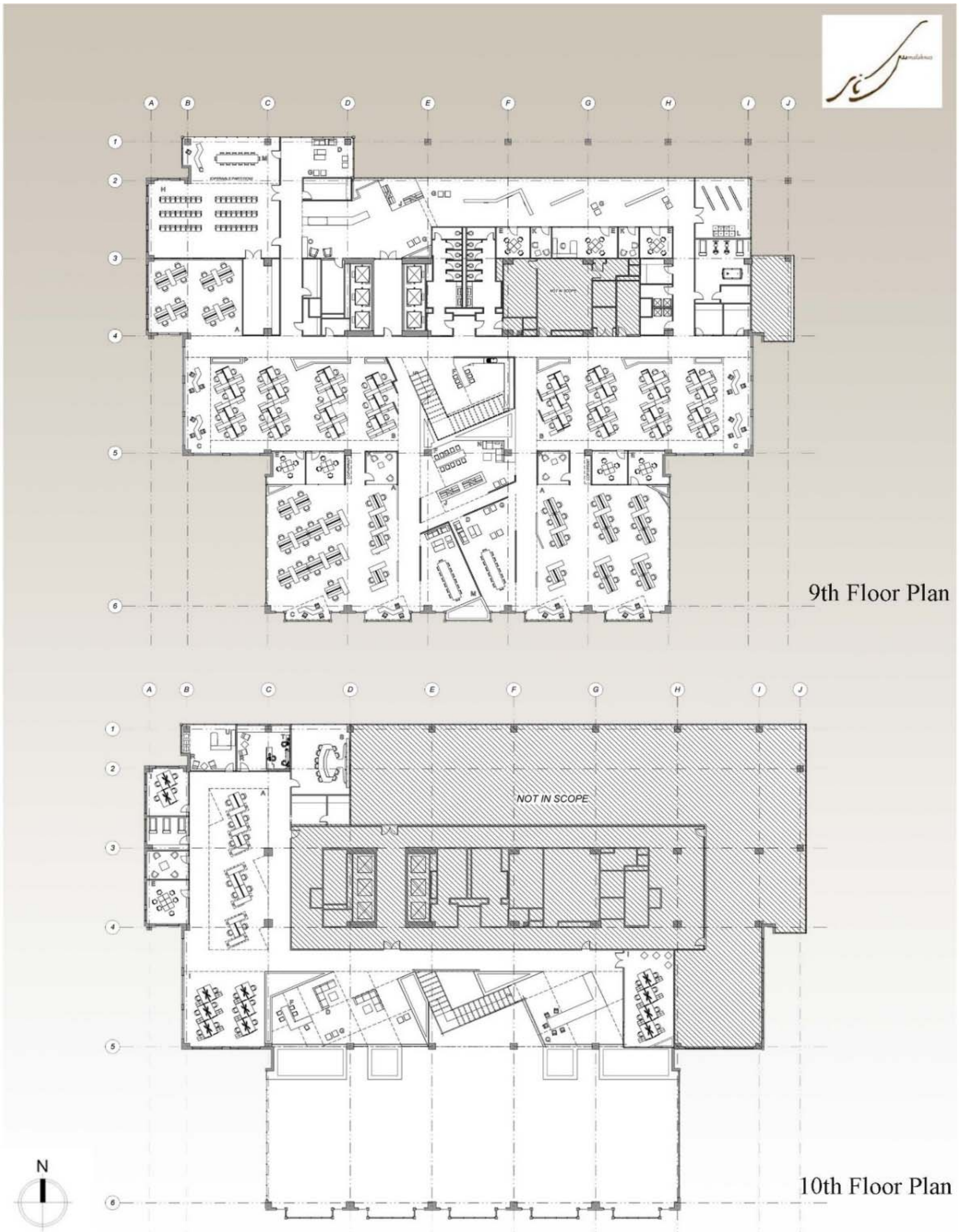
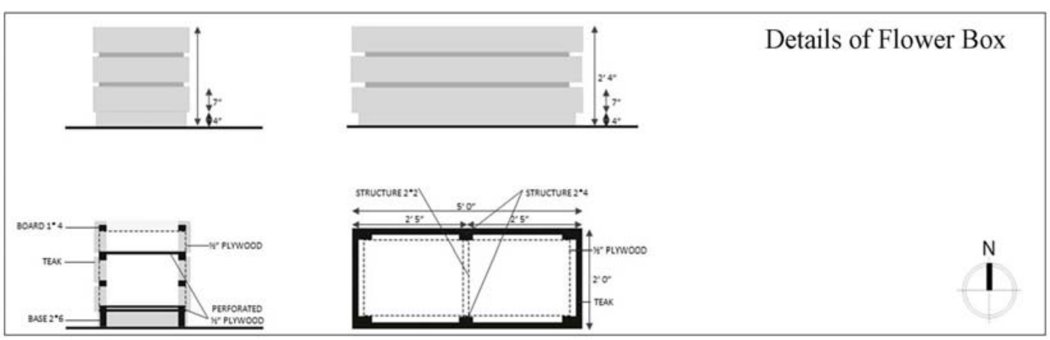


Figure 39. Design Proposal

Perspectives


Offices


Offices


Details of Flower Box
7"
4"
2' 4"
7"
4"
BOARD 1*4
TEAK
BASE 2*6
½" PLYWOOD
PERFORATED
½" PLYWOOD
STRUCTURE 2*2
STRUCTURE 2*4
5' 0"
2' 5"
2' 5"
½" PLYWOOD
2' 0"
TEAK
N

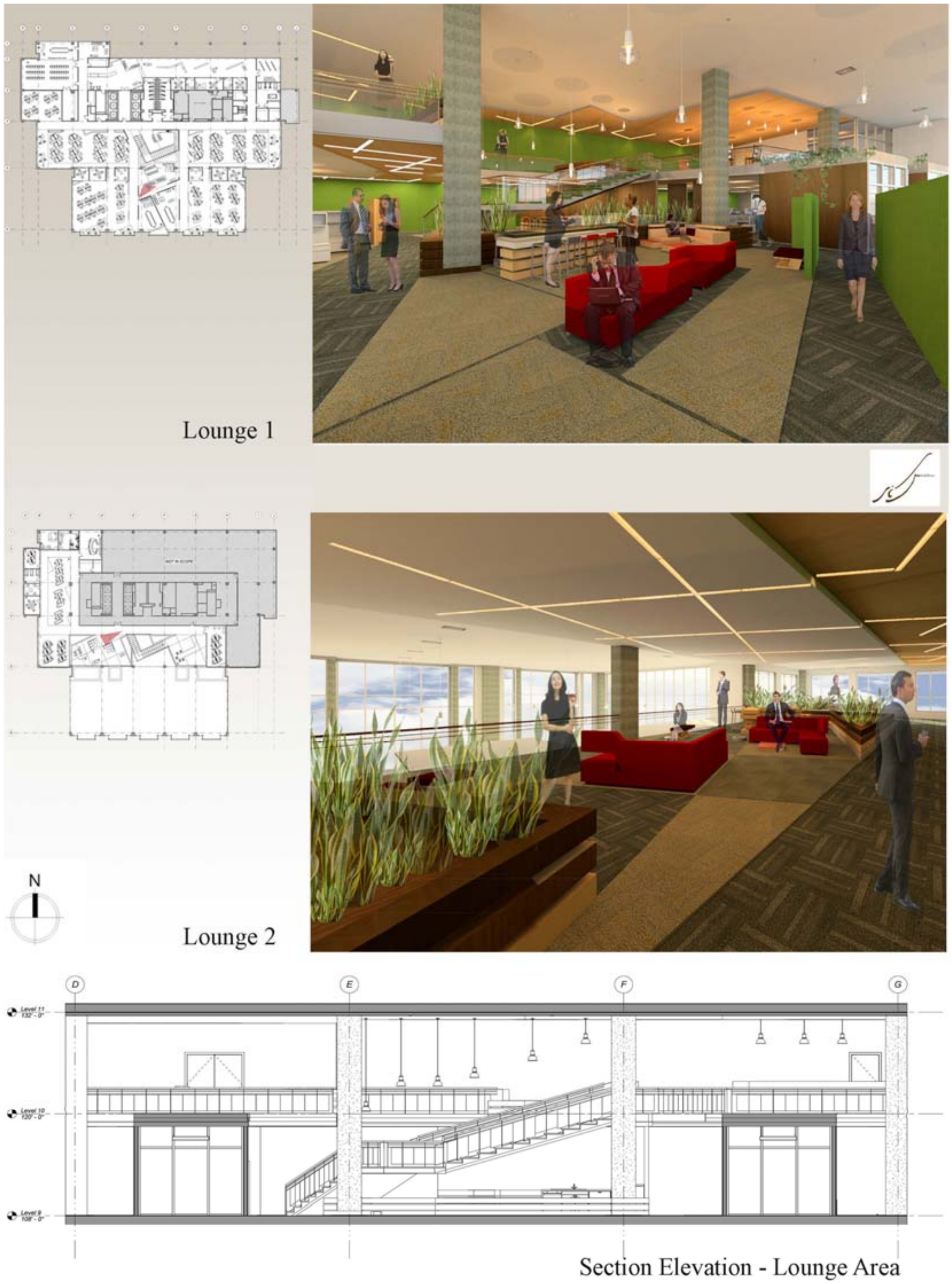


Figure 40. Perspectives

APPENDIX B

STUDIO IAR 602

Studio IAR 602- Models of Workstation Partitions in Three Different Heights (60”, 48”, and 42”)

Concept: My planning and design follow the LEED credits that covers daylight sufficiency and excessiveness in order to achieve maximum daylight credits and therefore increase energy savings: Maximizes diffuse daylight sufficiency & minimizes daylight excessiveness (glare). The detailed models of workstation partitions in three different heights (60”, 48”, and 42”) within an open plan office were designed based upon annual climate-based daylighting simulation results.

Designing unique workstation partitions according to the needs of each direction (north, south, west and east) is required due to daily and annual change in sun position and sky condition. In this project, the height of partitions are manipulated in order to develop workstation layouts that cover the daylighting needs of existing open plan offices to achieve maximum daylight credits in LEED and increase energy savings. Moreover, the color of these workstation partitions are a combination of green, blue and blue-green based on the current literature review in order to promote harmony and balance, decrease energy levels, and inspire innovation in an office environment where innovation is a key component.

Precedent Study

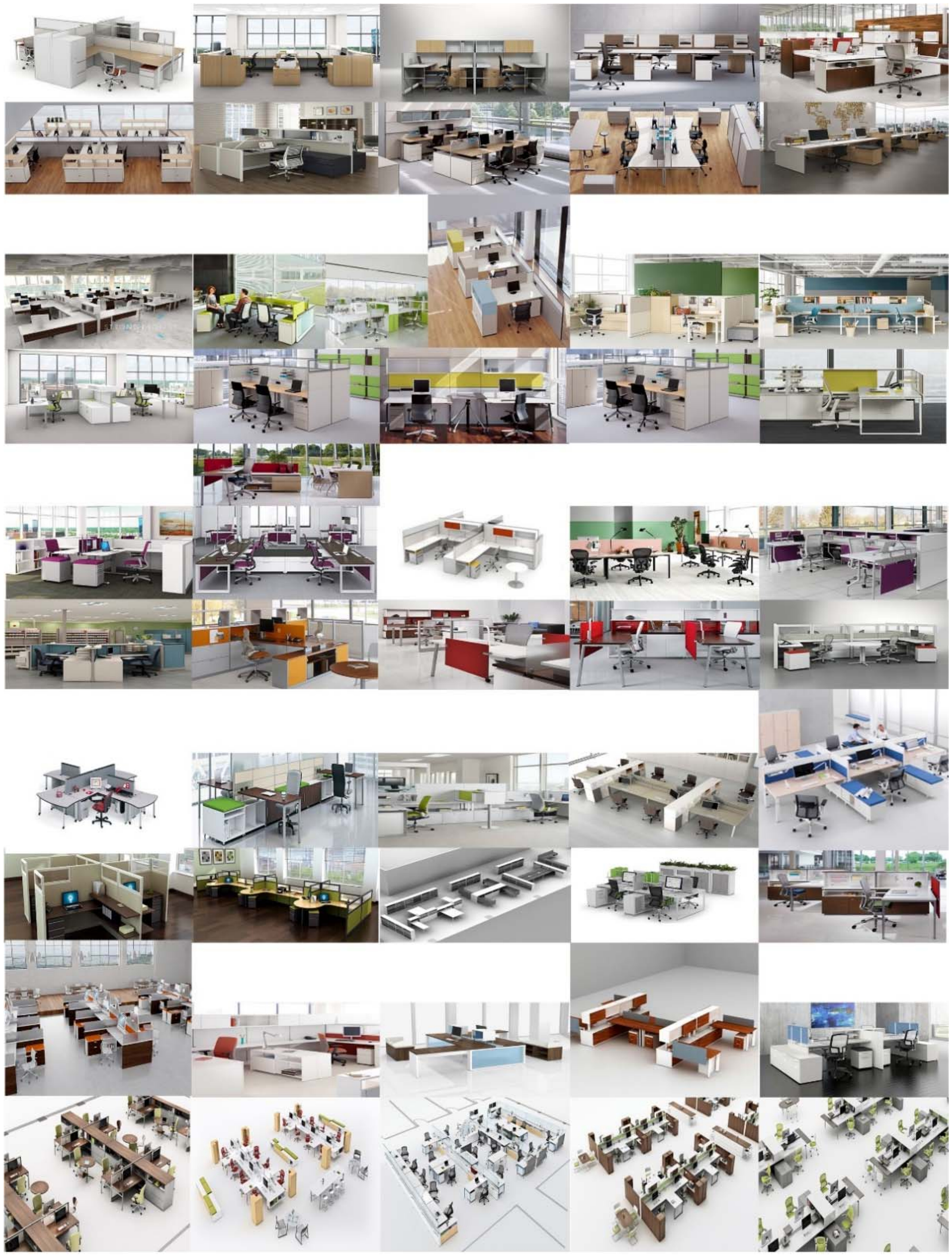


Figure 41. Precedent Study

Programming

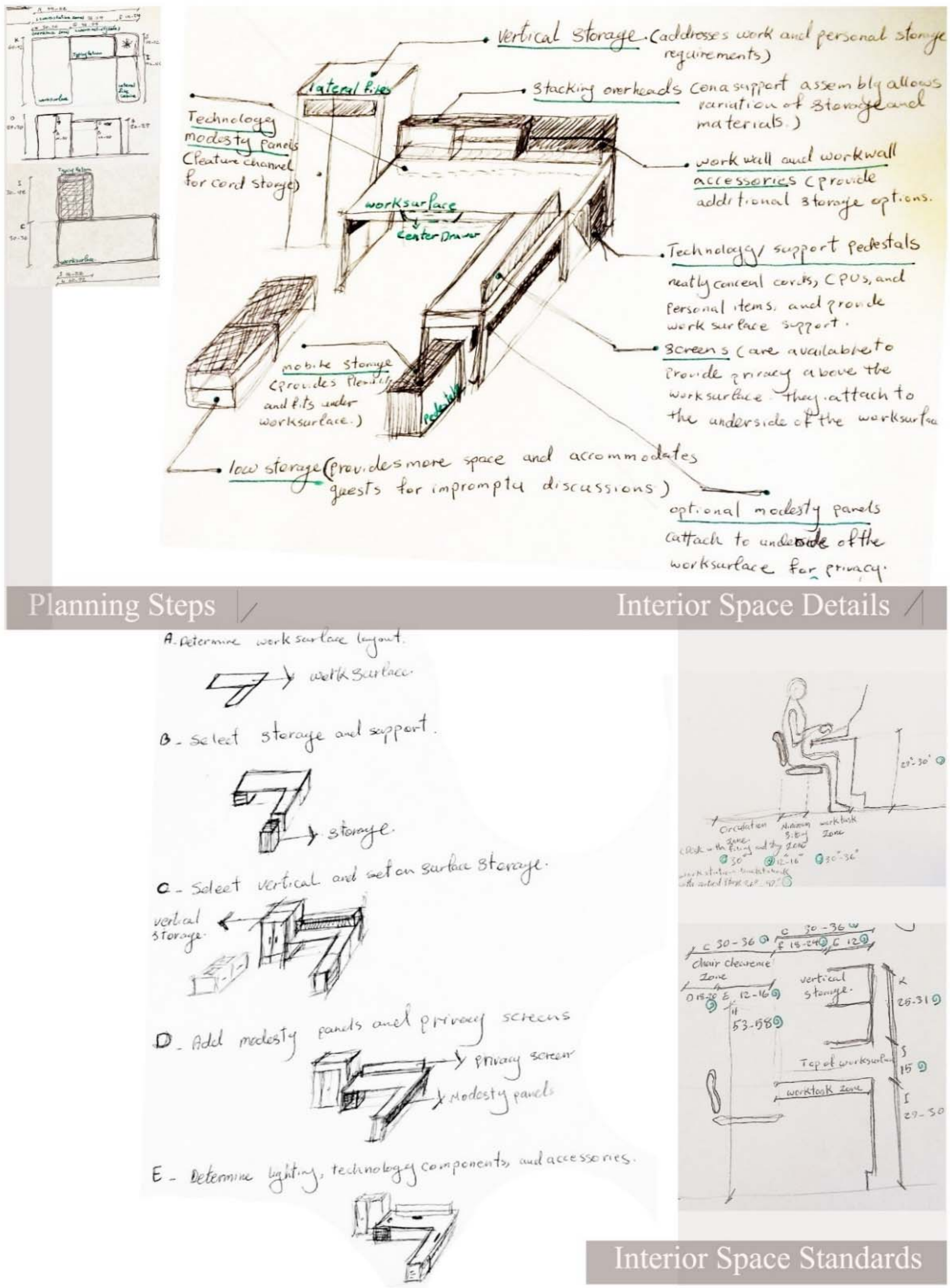
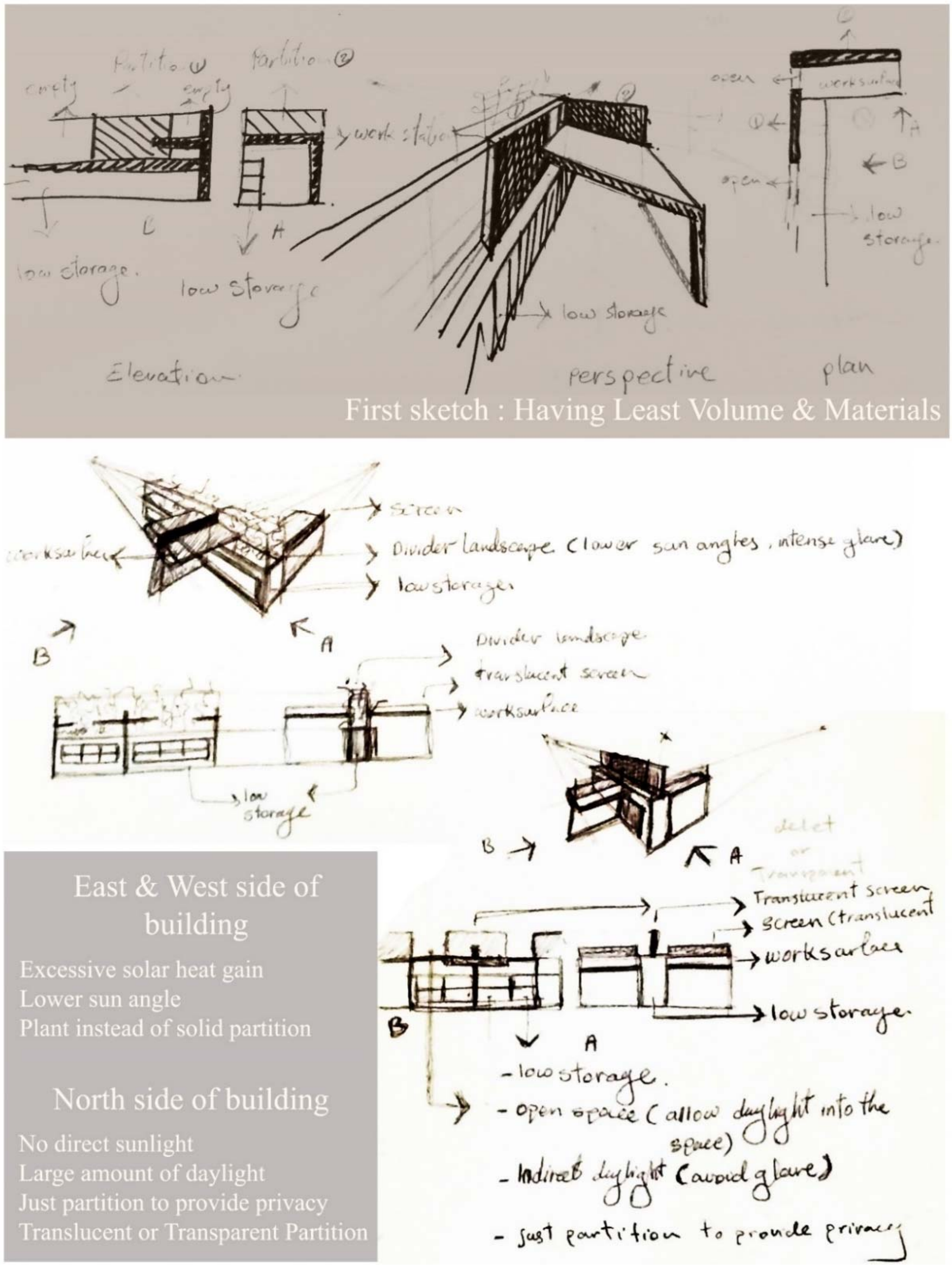
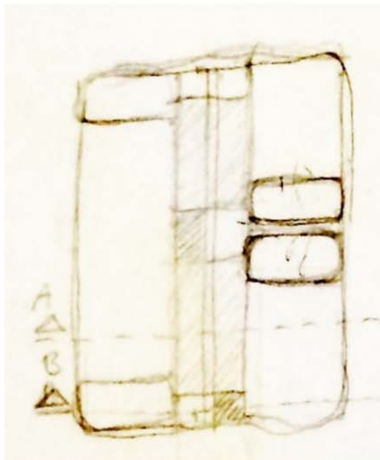


Figure 42. Programming

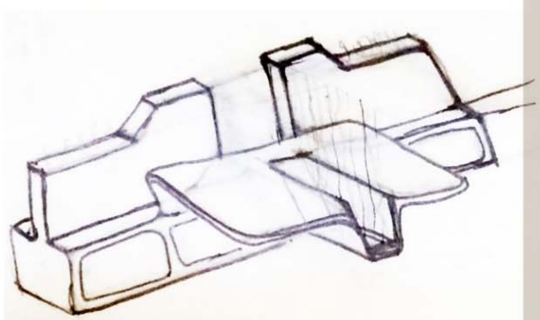
Schematic Design



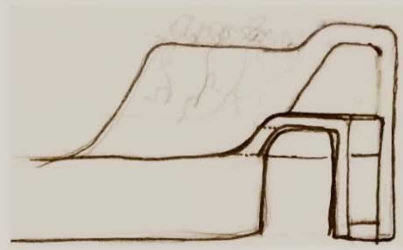
Some Sketchs



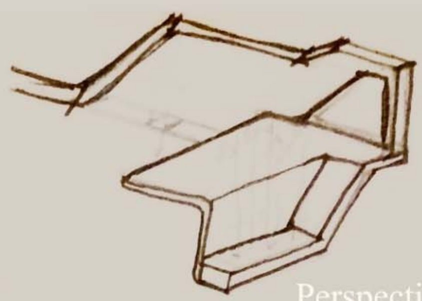
Plan - Spine Layout



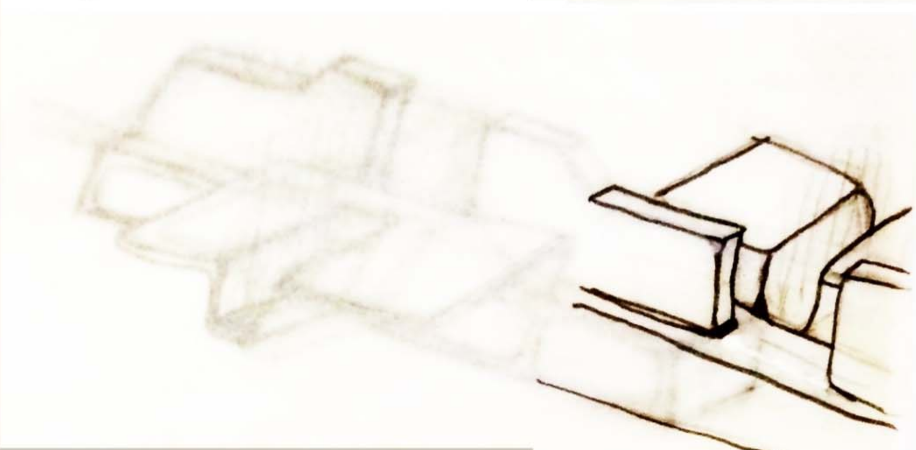
Perspective



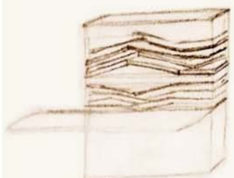
Elevation

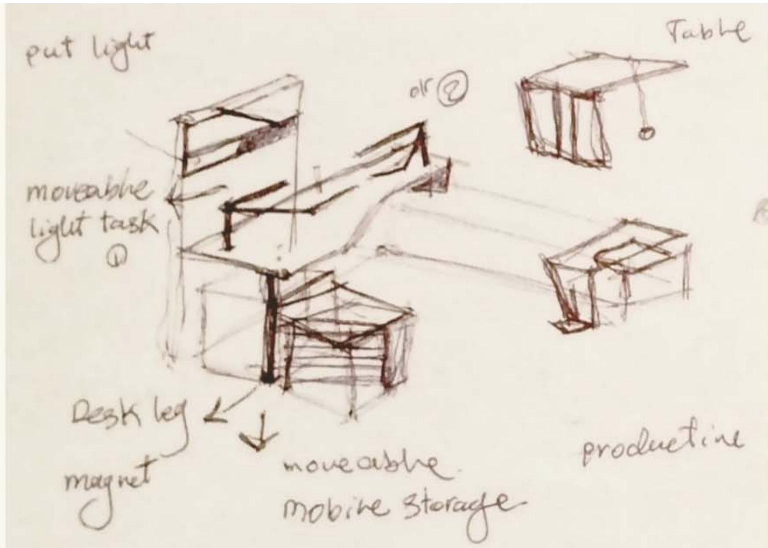


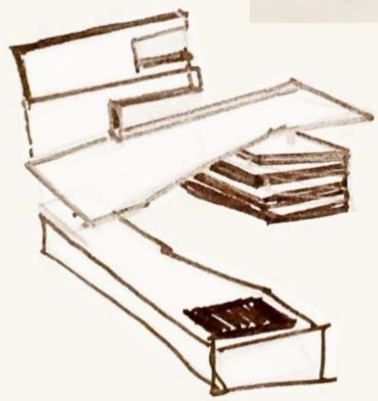
Perspective

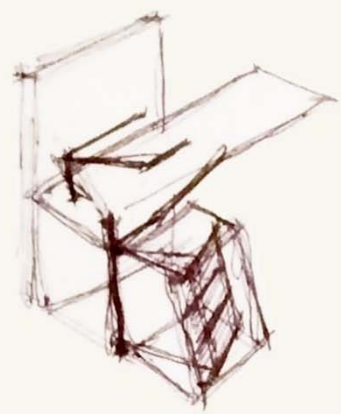


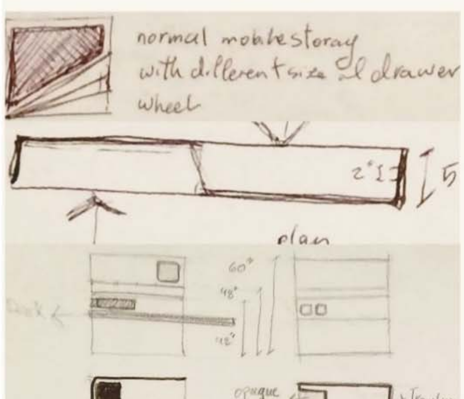
Schematic Design

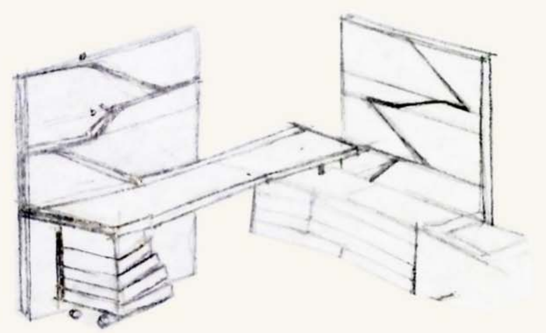












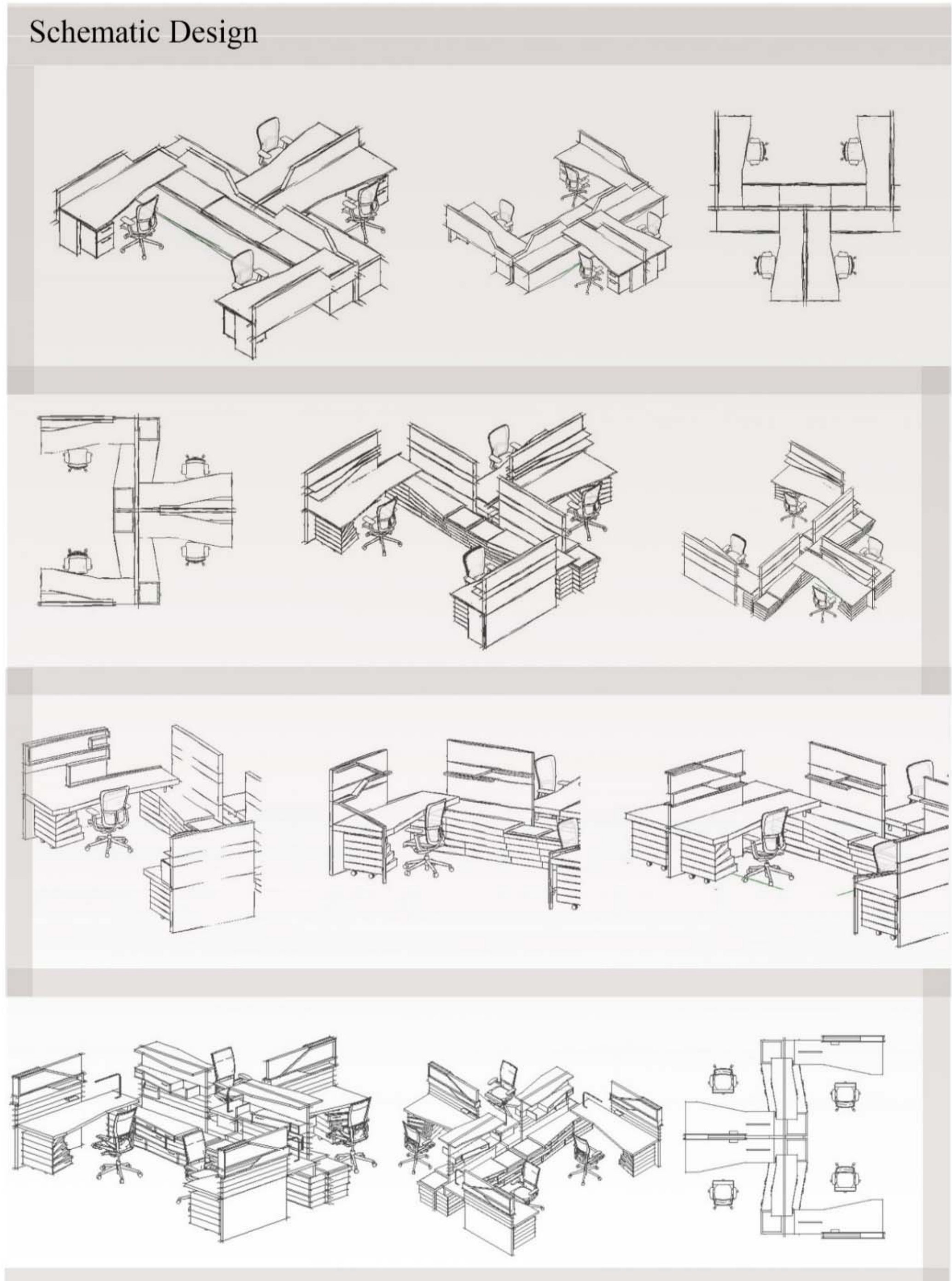
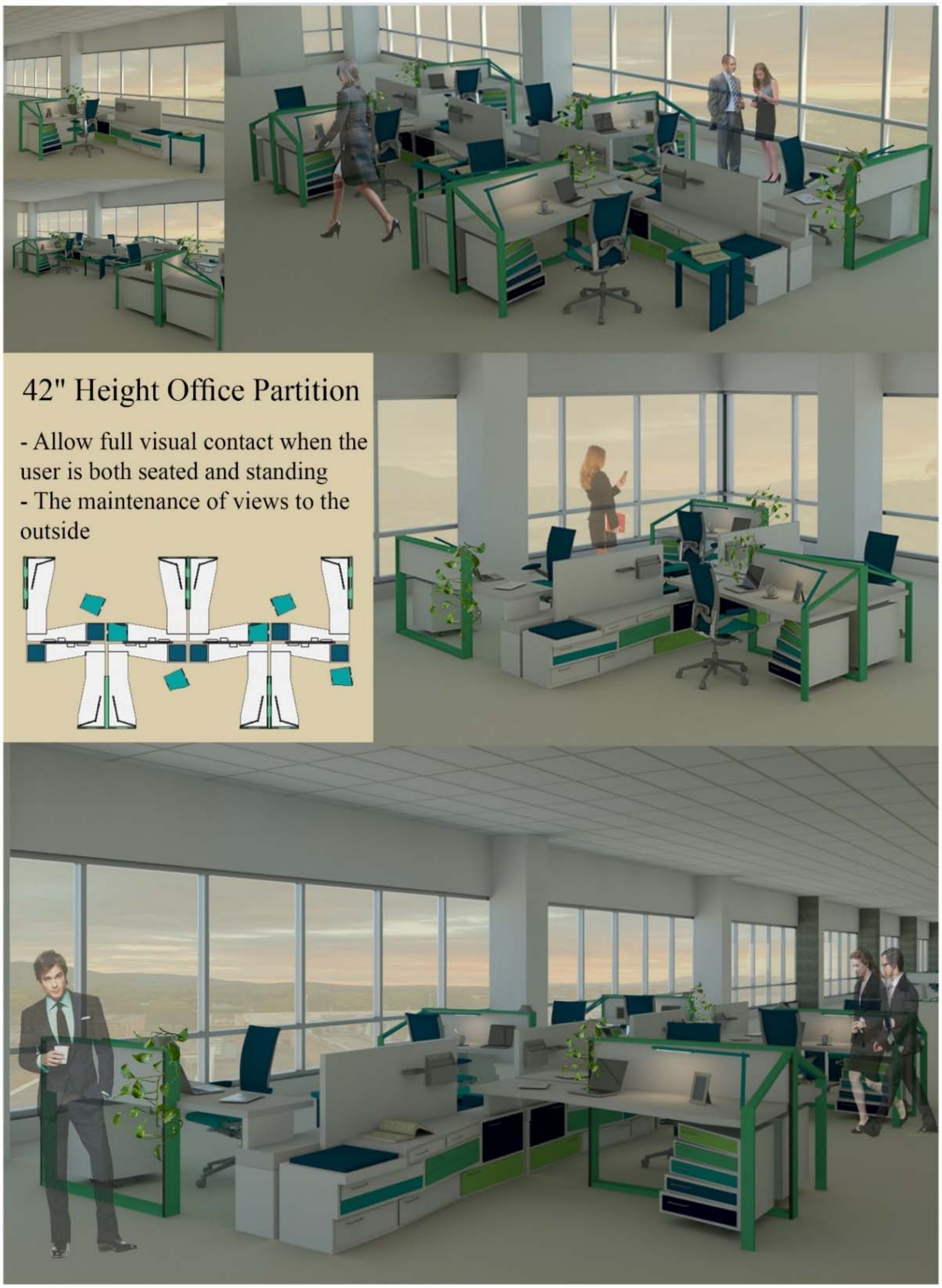
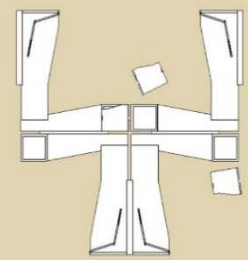


Figure 43. Schematic Design

Design Proposal


42" Height Office Partition
- Allow full visual contact when the user is both seated and standing
- The maintenance of views to the outside



48" Height Office Partition

- Provide partial seated privacy

- Create a sense of enclosure

- Provide full visual contact when the user is standing

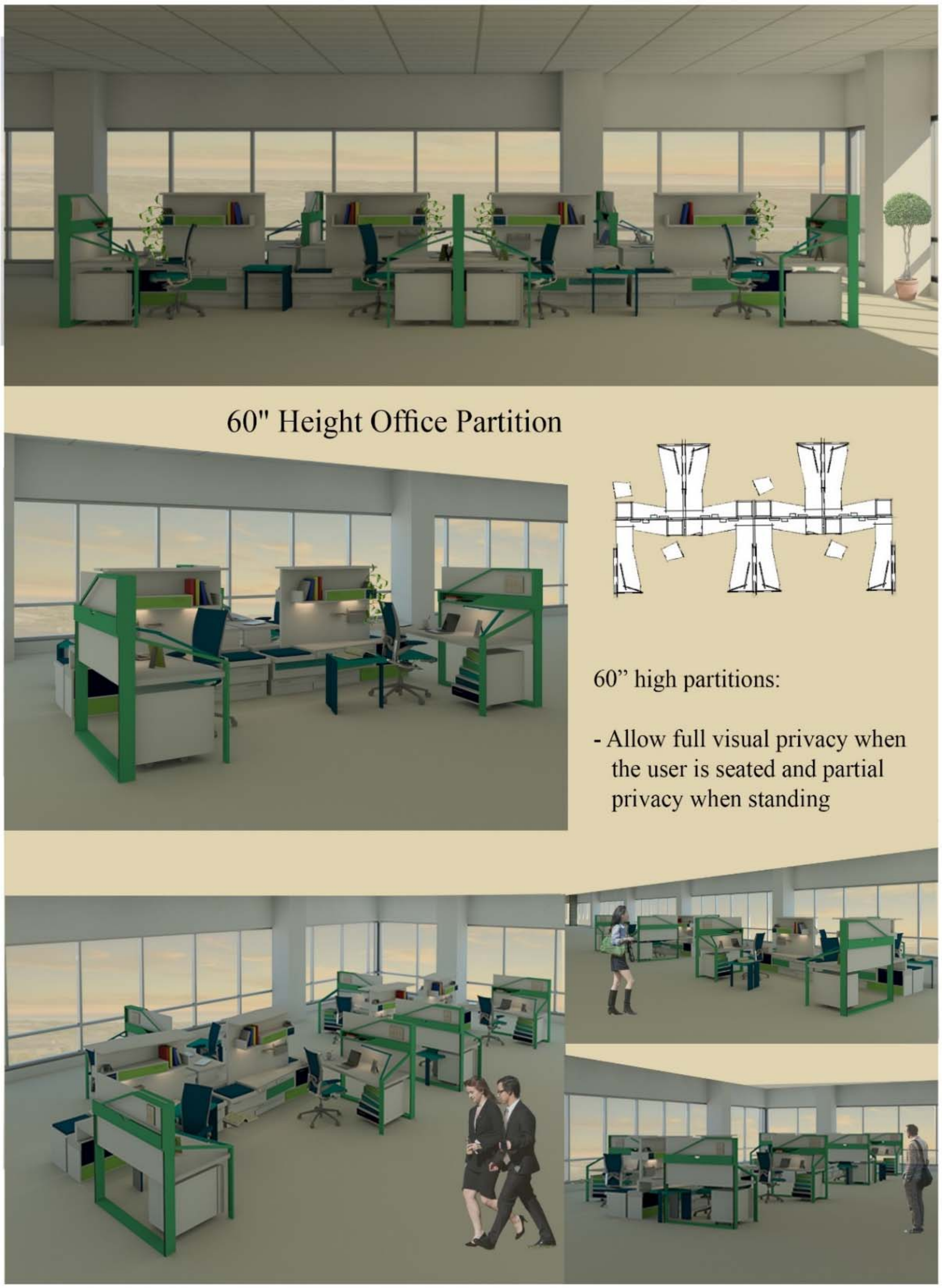


Figure 44. Design Proposal

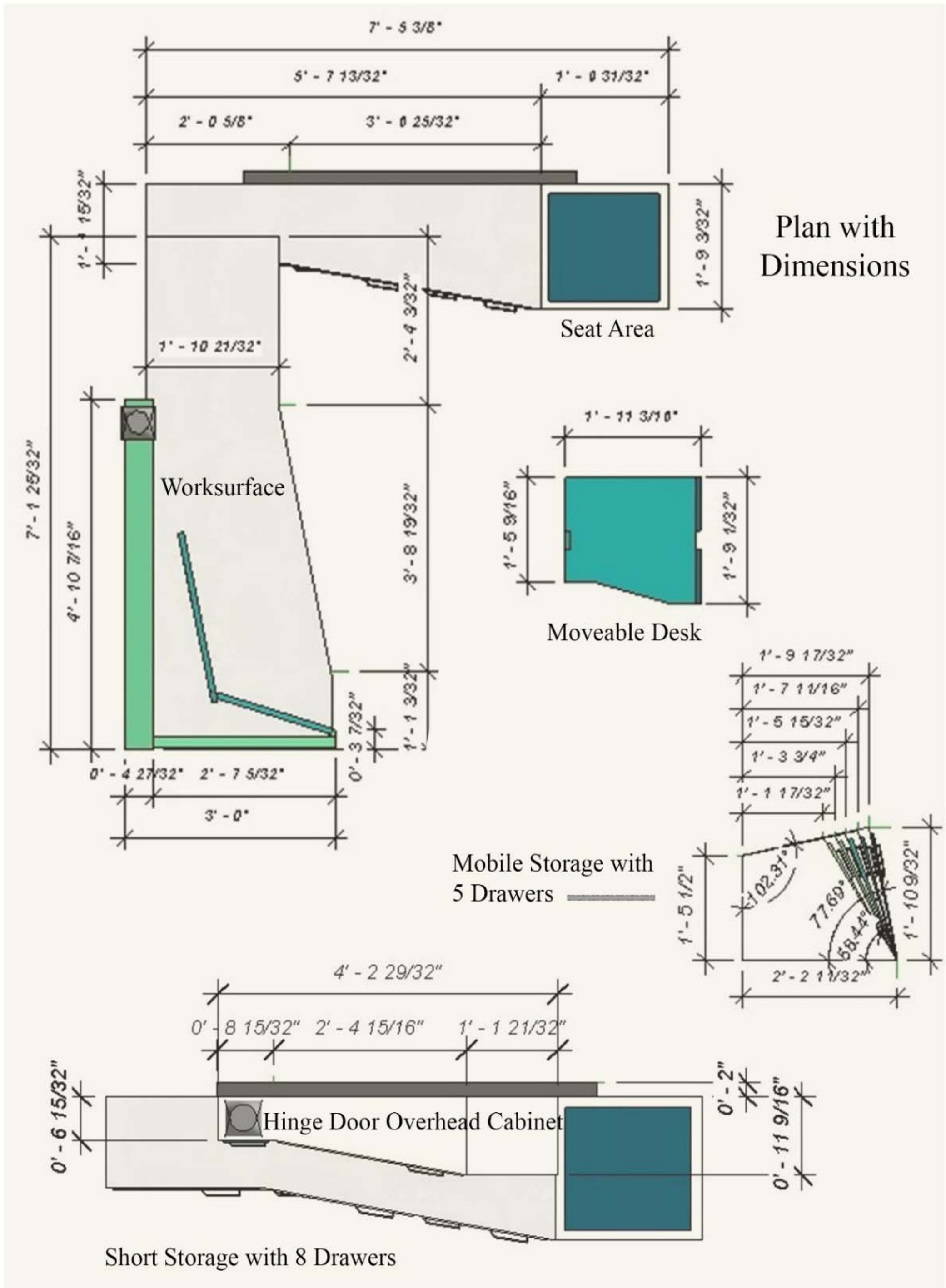


Figure 45. Plan with Dimensions

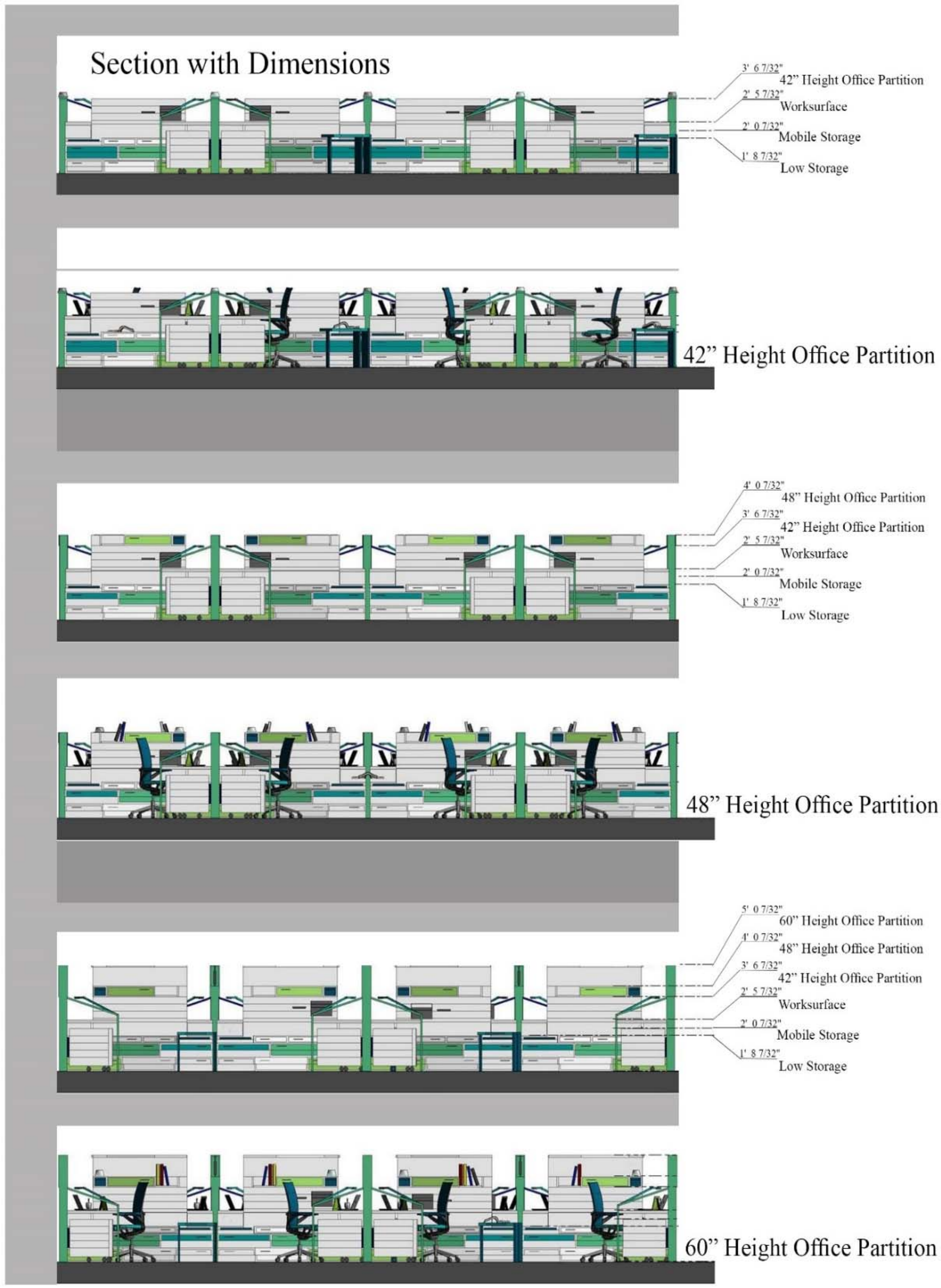


Figure 46. Section with Dimensions

Details of Workstation
Material of Workstation is Polyethylene
Ecological characteristic:100% recyclable
Steelcase - Seating Upholstery
Maya Blue 5091
Blue Jay 5098
Curvilinear Worksurface
Half - Depth End
Task Light
Column Base
Moveable Desk
Bluish and Greenish tones Color
Folding Desk Leg
Wheels under Leg

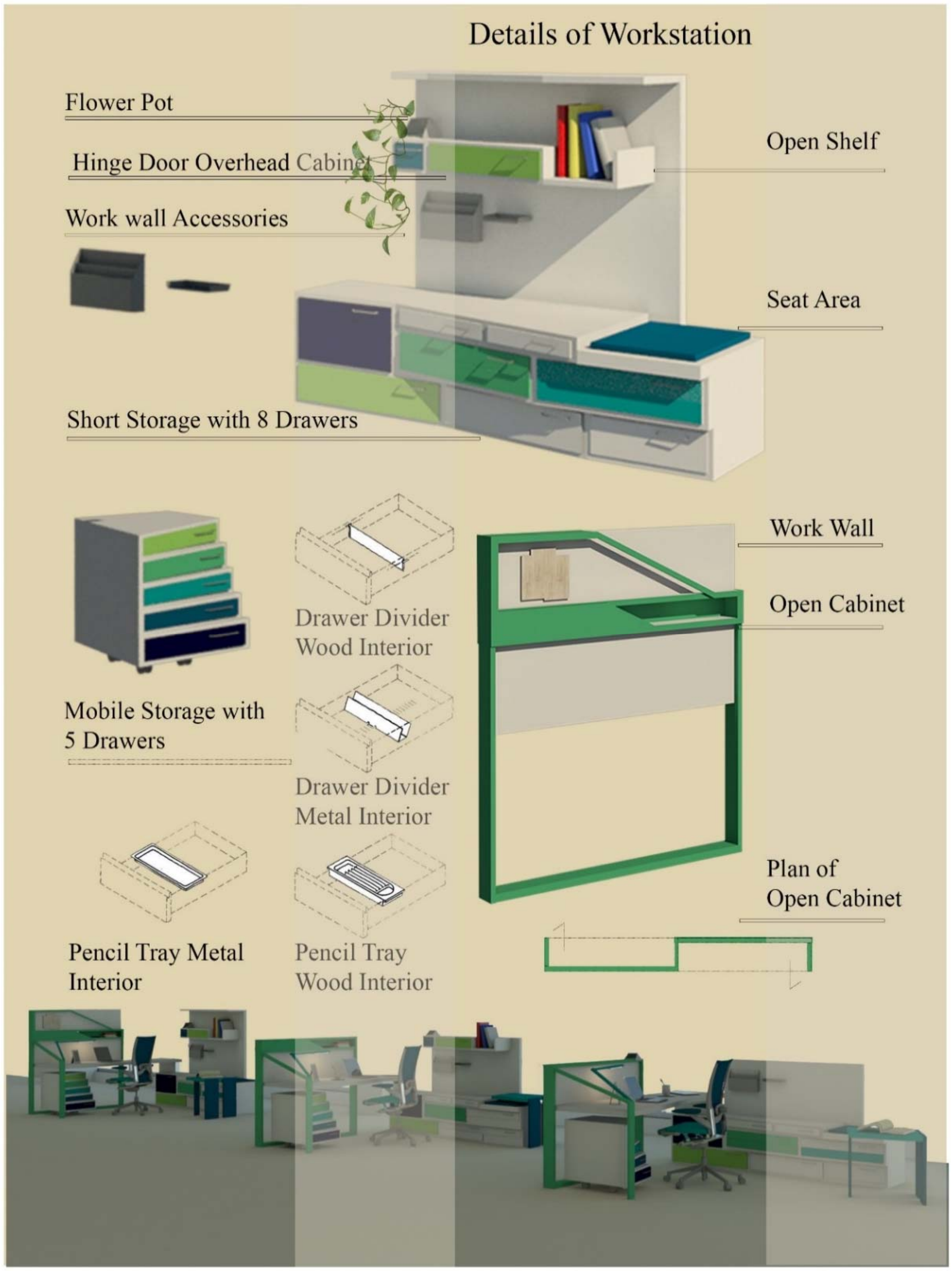


Figure 47. Details of Workstation

APPENDIX C

COMPARING (ASE) AND (sDA) (1)

Comparing (ASE) and (sDA) Results of 60 Scenarios of Partition Design on Four Facades (north, south, east, and west)

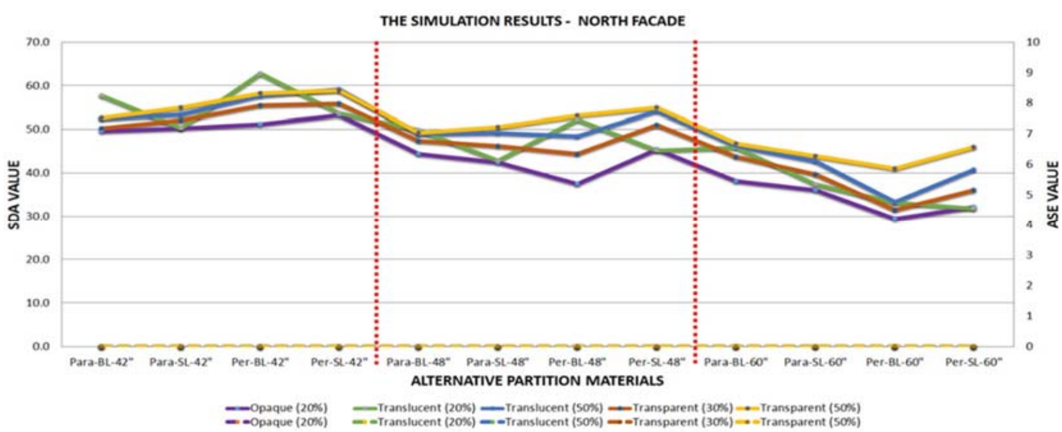


Figure 48. Comparing ASE and sDA Results of 60 Scenarios- North Façade

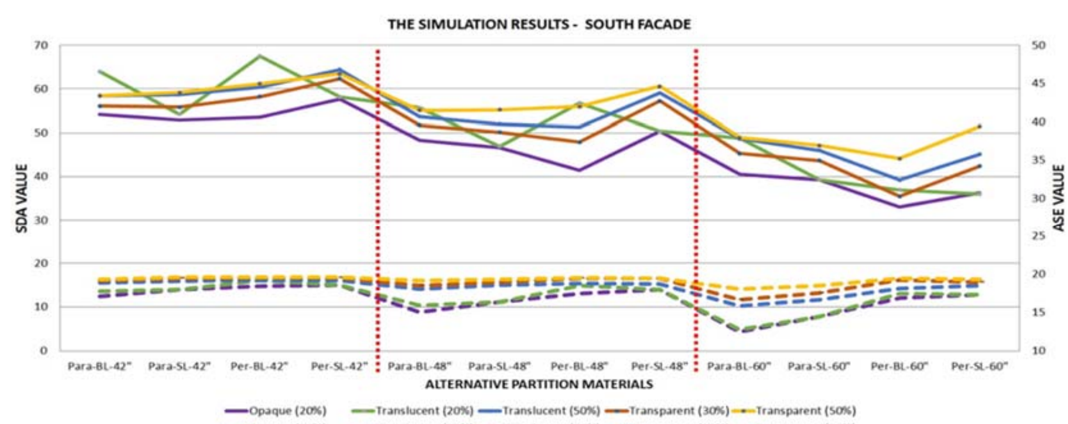


Figure 49. Comparing ASE and sDA Results of 60 Scenarios- South Façade

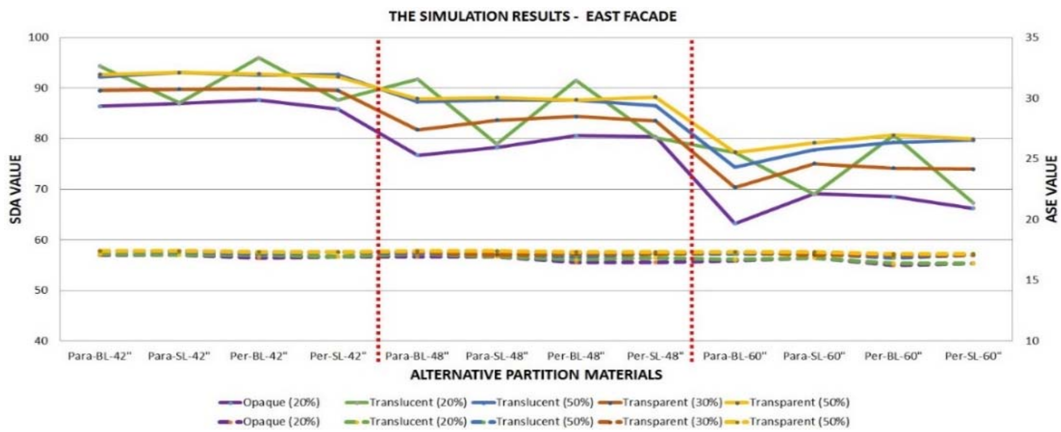


Figure 50. Comparing ASE and sDA Results of 60 Scenarios- East Façade

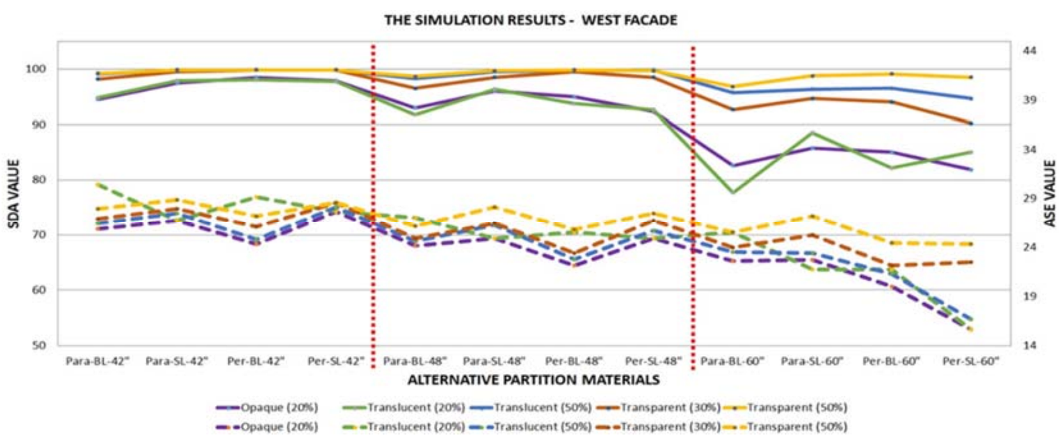


Figure 51. Comparing ASE and sDA Results of 60 Scenarios- West Façade

APPENDIX D

COMPARING (ASE) AND (sDA) (2)

Comparing (ASE) and (sDA) Results of 60 Scenarios of Partition Design by focusing on Height of Partitions, Orientations of Workstation Partitions, Shape of Layouts, and Materials.

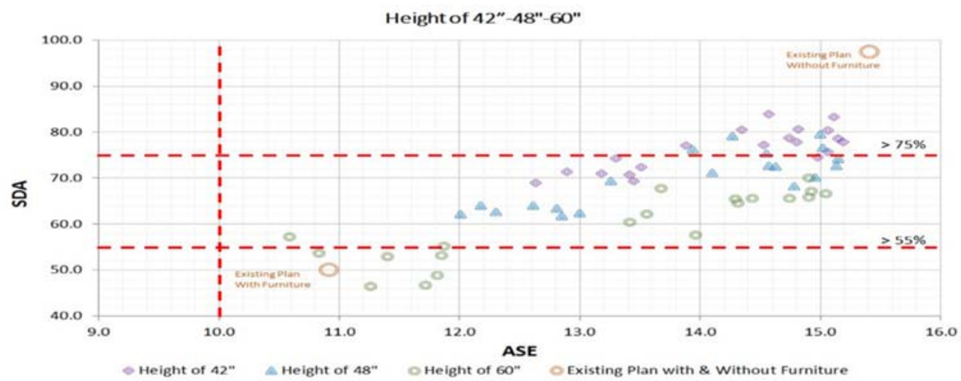


Figure 52. Comparing sDA & ASE Results By Focusing on Height of Partitions

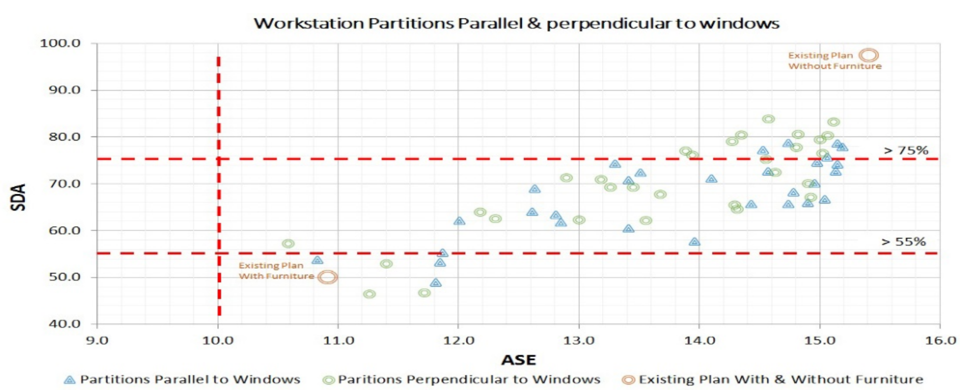


Figure 53. Comparing sDA & ASE Results By Focusing on Orientations of Workstation Partitions

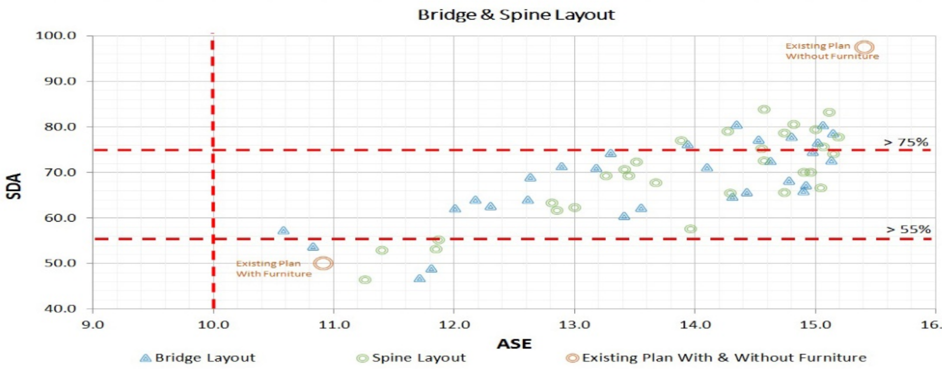


Figure 54. Comparing sDA & ASE Results By Focusing on Shape of Layouts (Bridge and Spine)

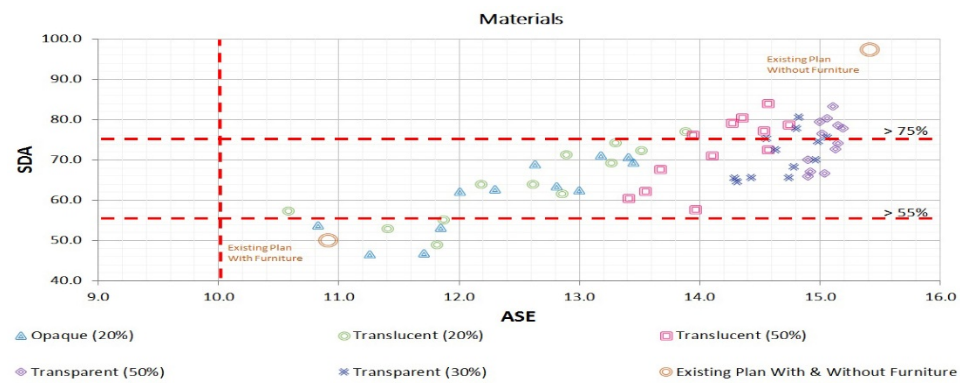


Figure 55. Comparing sDA & ASE Results By Focusing on Materials