Beyond Illumination:
Aesthetic Perception of Daylight in Architecture

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Stephen Boleska
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Problem Statement

We perceive daylight in architecture as a dynamic and expressive luminous composition, and yet photometric studies often evaluate daylight for its ability to provide adequate illumination for visual performance. While there is a consensus on lighting requirements for task performance as established by societies such as the IESNA, it is also known that when a design follows these illumination requirements, it does not automatically achieve visually appealing and stimulating environments. A reason for this is that most daylight metrics were developed to improve energy efficiency by replacing electric light, or to avoid human discomfort such as glare. However, this quantitative approach places a disproportionate emphasis on adequate illumination and disregards the possibility that dynamic luminous effects can provide a positive and appealing visual impact on our impression of space.

Thesis Statement

Contemporary architecture often employs full glass curtain walls to permit daylight that is not purposefully controlled and manipulated, thereby losing opportunities to create dynamic and expressive luminous compositions. Although these transparent envelopes may deliver an abundance of natural light that may ensure adequate illumination, they do not articulate how light is delivered. Careful control and manipulation of light through architectural openings and forms create a rich and dynamic composition of light resulting in aesthetically pleasing and stimulating environments. The control of natural light is essential to produce a heightened experience and develop a perception of space that is visually appealing, uplifting and imbued with meaning.

01. Research

Figure 1: Snøhetta's Glacier-Inspired Deloitte Office Building in Oslo. The fragmented openings of the building envelope creates luminous effects of light and shadow, resulting in a stimulating work environment.
Source: https://www2.deloitte.com

Figure 2: Mount Stephen Club Hotel Montreal 2017. Source: https://www.archiexpo.com

Abstract

This thesis is concerned with natural light in architecture. In particular, it examines the aesthetic[1] perception of daylit indoor environments.

When designing interior spaces, architects rely heavily on photometric measurements and illumination recommendations to make lighting choices. The IESNA (Illuminating Engineering Society of North America) and CIE (Commission Internationale de l'Éclairage) are two organizations that develop these recommendations based on rese pealing spaces. Although these requirements are important in providing visual comfort and illumination levels for specific tasks, this paper does not seek to assess their value. Indeed, daylight considerations need to go beyond providing adequate illumination and must explore how to provide visual comfort and aesthetic appeal.

We must now establish an important distinction: A room with enough light for performing certain tasks can be considered adequately illuminated whereas a space that creates visual interest can be described as visually appealing. An adequately illuminated space satisfies the recommended illumination requirements for the spatial function but does not necessarily result in luminous effects that are both stimulating and appealing.

Although aesthetic is subjective in nature, it is important to consider the visual interest in conjunction with illumination recommendations to develop a more holistic daylight design. The spaces we regularly occupy, homes and offices, seldom explore the possibility to provide aesthetic and expressive luminous effects. These spaces often employ glass curtain walls that permit an overabundance of uniform light that is not purposefully controlled or manipulated, losing the opportunity to create luminous effects, contrast, focus, and diversity. Visual and perceptual aspects of light are essential to the spatial experience of architecture and will be more visually influential than other more defined criteria such as illumination levels.

This thesis seeks to explore how architecture can affect the aesthetic perception of a daylit indoor space. This paper will experiment with the design of various openings to compare a range of illumination conditions.

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1 The word aesthetics comes from the Greek word aisthetikos, referring to sensory perception and understanding or sensuous knowledge. Oxford dictionary defines aesthetics as: concerned with beauty or the appreciation of beauty. In the context of this paper, the author defines aesthetics as the visual interest and perceptual aspects in architectural daylighting that renders a space interesting and meaningful through use of dynamic luminous compositions of light and shadow.

The work presented in this study considers two types of daylighting designs: windows as a basic element to permit and control natural light (simple and singular openings) and building envelopes as a series of openings to disperse natural light into an interior space (complex and multiple openings). To assess the aesthetic perception of a daylit architectural space, six aesthetic descriptors were considered: Contrast, Uniformity, Patterns, Coherence, Stimulation, and Spaciousness. The author has created this list of descriptors based on perceptual attributes that were observed in the experiments, although there may be more, these are considered fundamental to the development of this thesis.

Considering that we spend most of our daylight hours at the workplace – depending on location and season – the following spatial environment is the focus of this study: a studio workspace.

This thesis presents the results and discussions of a collection of daylit environments observed in two different experimental procedures. In total, 32 different illumination conditions generated by various openings were assessed and then surveyed by 28 participants[1]. The experiments were designed to observe and evaluate the impressions of a studio space under different lighting conditions where openings that delivered light varied in size, shape, position, and scale. The conclusion of this study confirms that the design of architectural openings has a significant and influential impact on the subjective aesthetic impression of a space. Moreover, the collective findings from the survey suggest that photometric measurements – illumination levels – alone are not sufficient indicators to judge and assess the six particular aesthetic qualities. Although photometric studies are necessary, other non-metric attributes, such as luminous effects resulting from the form of architectural openings, influence aesthetic quality

Natural light in relation to the aesthetic of a space is still an emerging topic as there is still a lot we can explore. The aim of this thesis project is to shed light on how the composition of natural light contributes to the meaning and aesthetics of architectural space. By using the collected information from this study, an office building will be designed to explore the aesthetic attributes in relation to spatial functions.

2 An empirical study of each experiment was conducted by 28 design and architectural professionals. Designers and Architects understand the language of space and light, for this reason they were selected for the initial experiment.

Figure 3: Deloitte Tower Montreal - Contemporary Canadian Office Building. Montreals newest urban commercial highrise, Deloitte tower completed in 2015. Source: photography by author.

Motivation

> *"In our time, light has turned into a mere quantitative matter and the window has lost its significance as a mediator between two worlds, between enclosed and open, interiority and exteriority, private and public, shadow and light. Having lost its ontological meaning, the window has turned into a mere absence of the wall."*
>
> – PALLASMAA, J. (2012) The Eyes of the Skin; Architecture and the Senses p.47

Light is an important parameter enabling us to visually navigate our environment, yet how light is treated also influences our impression and experience of space. In the experience and opinion of the author, daylight in residential and commercial architecture is often disregarded as an important aesthetic element of design.

Moreover, architects put a disproportionate emphasis on obtaining minimum illumination levels and not expressive luminous effects. Our commercial office buildings are designed with large glass curtain walls that tend to permit an overabundance of evenly dispersed light (figure 3). These transparent envelopes also deprive the occupants of intimacy and a sense of place. As architect Luis Barragan stated in Clásico del Silencio, "The use of enormous plate windows deprive our buildings of intimacy, the effects of shadow and atmosphere. Architects all over the world have been mistaken in the proportions which they have assigned to large plate windows or spaces opening to the outside" (Barragan, 1989). Although this transparency may ensure a space is adequately illuminated, it limits the potential to create luminous effects that enthuse our visual impression of the space (figure 4). An adequately illuminated space is not necessarily visually appealing or stimulating. This argument serves as motivation for this thesis project.

Figure 4: Interior view of a contemporary adaptive work space. The use of full height curtain wall provides uniform adequate illumination, but arguable the lack of luminous diversity is uninspiring. Note that most roller shades are drawn, blocking natural light from the upper portion of the opening that would penetrate deeper into the environment, and daylight is permitted below the work surface.
Source: https://www.theglobeandmail.com.

Introduction

When designing a space, there are several significant factors to consider: the volume of the space, materials, function, circulation, and number of users. Either previously considered or not, light is another important and expressive architectural element that contributes to the visual impression of space; it does this by enhancing forms, accentuating textures, and creating contrast, focus, and patterns (figure 5). Consequently, the perceived aesthetic of a space is defined by all of these factors, in particular by light, as Steven Holl[1] states in an article on luminosity, “Space is oblivion without light. A building speaks through the silence of perception, orchestrated by light. Luminosity is as integral to its spatial experience as porosity is integral to urban experience” (Holl, 2006).

In daylit spaces, our visual impression of architecture is significantly influenced by the dynamic condition of our surrounding environment. Conditions, such as time of day, season, climate, and weather are in continuous fluctuation, and the ensuing lighting conditions can create impressive luminous effects that stimulate our visual perception of space. In his seminal book titled The Eyes of the Skin: Architecture and the Senses, Juhani Pallasmaa discusses how our vision is stimulated by light and shadow. He compares the dark focus in the painting by Caravaggio to the shadows cast by architecture. He states, “In great architectural spaces, there is a constant breathing of shadow and light; shadow inhales and illumination exhales light” (Pallasmaa, 2012, p.51). This quote adds to the notion of aesthetics as defined by the author, where dynamic luminous effects of light and shadow can enhance the aesthetic perception of space. Unlike artificial light, which can be controlled to create desired effects, its static attributes can never match the “nuance of mood created by the time of day and the wonder of the seasons” (Steane, 2011, p.7).

Moreover, the location of a building, latitude, orientation, elevation, and surroundings affect the intensity and duration of daylight throughout the year, while local weather conditions further affect its variability and strength. Although there are numerous daylight studies that can predict daylight in controlled conditions, such as changes in season, changes in time of day, and changes to urban environments, there are also site conditions that are impossible to predict. Surrounding site conditions such as neighbouring structures can direct or obstruct how daylight will enter an interior space, and it is often not possible to predict how these circumstances may change over time.

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1 This awareness is repeatedly demonstrated in the work and writing of American architect Steven Holl, whose constructs exemplify the fundamental idea that “the perceptual spirit and metaphysical strength of architecture are driven by the quality of light and shadow shaped by solids and voids, by opacities, transparencies and translucencies. Natural light, with its ethereal variety of change, fundamentally orchestrates the intensities of architecture and cities”. (Holl, 2007, p. 63)

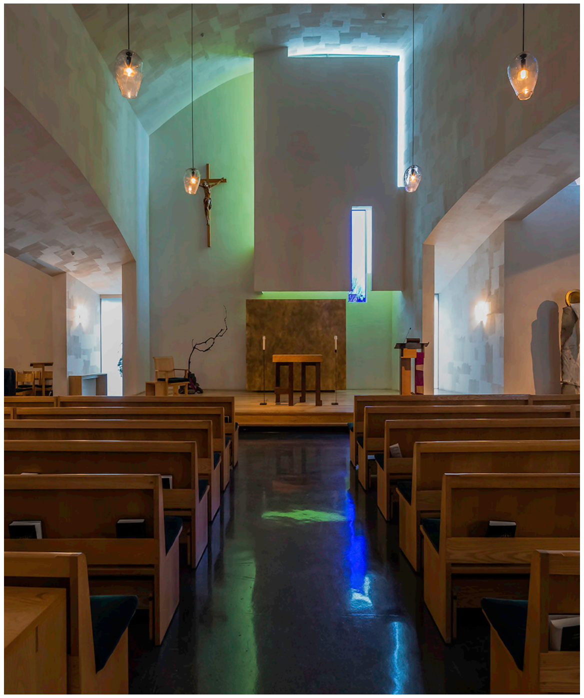


Figure 5: Chapel of St. Ignatius (1997) by Steven Holl Architects. Source: www.stevenholl.com

IESNA Recommended Illuminances	
	Illuminance
Space Type	(lux)
Open Offices	300 to 500 (50 to 100 with task lighting)
Private Offices	500
Conference Rooms	300
Corridors	50
Restrooms	100
Lobby	100
Copy Rooms	100
Classrooms	300
Kitchen	500
Labs	500
Computer screens	30

Figure 6: List of recommedend illumination levels. Source: IESNA Handbook 9th Edition

The altitude, angle, and color of daylighting varies with the time of day, orientation, and latitude. Canadian cities with large commercial buildings such as Toronto, Vancouver, Montreal, and Ottawa are all located between latitudes 43° N and 53° N. At this latitude – Northern hemisphere – daylight entering from the East is strongest in the morning and tends to be of low altitude with soft, long shadows. Daylight from the South is dominant in the morning to mid-afternoon and casts strong, sharp shadows. Daylight from the west is strongest in the late afternoon and early evening; it penetrates deep into buildings and can be overbearing. Daylight from the North tends to be shadowless, diffuse and neutral or slightly grayish most of the day and year.

Architecture is enriched by the temporal characteristics of natural light, yet it is most often valued simply for its ability to provide adequate illumination and evaluated by photometric measurements, which omit the possibility to create rich and diverse compositions of light and shadow. While there is some consensus on the minimum amount of illumination that is required for the human eye to perform visual tasks, as recognized by lighting standards (figure 6), it is less clear on how much diversity and luminous effects make an architectural space visually appealing.

Aesthetic judgements have been identified to be relevant to the evaluation of environments by different studies (Pellegrino, 1999). However, most studies seem to focus on using lighting metrics to assess light in a space. Pellegrino[1] (1999) argues that "many methods are used to quantify lighting, whereas there is no comprehensive and widely accepted method for the evaluation if its quality. Designers are provided with a variety of numerical criteria for assessing the effectiveness of their projects: illuminance, illuminance uniformity, luminance ratios, glare indices, etc. Even when they are all considered, the lit environment, while functional, will not necessarily be pleasant." Beyond its utilitarian function, there are also aesthetic attributes that need to be considered when evaluating an interior space. A well-lit space has the potential to create a meaningful connection between people and their surroundings and provide greater user satisfaction.

1 Anna Pellegrino is an Associate Professor at Politecnico di Torino, Italy. Her main research interests are all within the field of lighting: from lighting and control technologies to lighting applications and energy use, from lighting design to issues of light and health, visual comfort and material damage. She has been published in Daylight and Architecture Magazine #24 by Velux.com.

Figure 7: Serpentine Pavilion 2002 by Architects 2002 by Toyo Ito and Cecil Balmond.
Source: http://www.serpentinegalleries.org

Objectives

The main objective of this thesis is to shed light on the effect of architectural openings and lighting in interior spaces. This can be divided into two topics: The quantity of light delivered by openings and the quality of natural light.

This paper will introduce an experimental method for comparing architectural openings and illumination levels against subjective ratings of daylight compositions in an office workspace. This preliminary study will evaluate the luminous effects on subjective ratings for Contrast, Uniformity, Patterns, Coherence, Stimulation, and Spaciousness. This thesis reports empirical findings on how opening attributes affect the illumination levels (quantity) and aesthetic perception (quality) of indoor environments. Taking both perceptual qualities and illumination metrics is important to develop a complete understanding of daylight in architecture which can be of help for architects, designers, and future users.

Thus, the objectives of the present thesis are:

1. To shed light on the impact of architectural openings and the aesthetic judgment of an interior environment.

2. To compare the illumination levels of different openings.

3. To compare the luminous effects and conditions generated by different openings.

4. To survey the aesthetic perception of an indoor environment under different luminous conditions.

5. Combine the data to design a space that is both adequately illuminated and visually appealing.

Selection of Environment

We spend most of our time indoors, around 80-90% (Klepeis, 2001). This percentage includes both times spent at home and at the workplace, meaning we spend an average of 20 hours a day inside buildings (Leech, et al., 1996). A significant amount of daylight hours are spent at work, i.e. commercial office buildings (figure 8).

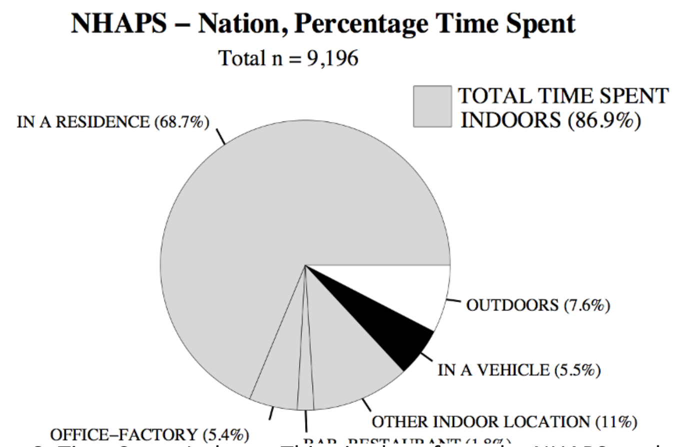


Figure 8: Time Spent Indoors. This pie chart from the NHAPS study shows that Canadians spend 86.9% of time indoors, plus another 5.5% inside a vehicle. Source: https://www.buildinggreen.com

Surveys of office employees consistently report that lighting is among the more important features in office design and that the quality of light can influence task performance, comfort, and well-being (Veitch, 2011). Yet there seems to be little research that focuses on the impact of windows (daylight distribution and effects) on the perception of the interior of any building type (Veitch, 2011). Commercial office buildings are commonly enclosed with glass curtain walls. The curtain wall becomes a non-mediating form of illuminating space, but if we control how light is permitted through the use of architectural screens and openings, we can control the experience and impression of space through light. In other building functions, i.e. secular, museum, and pavilion, luminous diversity plays a significant role in defining the design intent and spatial impressions (figure 7). This is important because the environments in which we spend most of our day affect our mood and well-being in addition to the comfort and efficiency, and the lighting quality of a space greatly influences these impressions and factors.

	Rank-based	Activity-based		Experience-based
	Perimeter	**Core**	**Efficient**	**Adaptive**
Characteristics	• Stationary, fixed work settings • Separation between work-space • Perimeter private office • Large formal and enclosed activity spaces • Prescribed circulation paths	• Open work settings • Connection among work-space, mid-to-low horizons • Interior private offices • Mixed, formal/informal, open/enclosed activity spaces • Long sight lines, natural light	• Compact, densified work settings • Low horizons • Few, small private offices • Small-scaled activity spaces • Close proximity, narrow pathways	• Varied work settings • Dual-function offices • Assortment of interwoven activity spaces • Ample conveniences and amenities • Social gathering spaces
Primary workspaces:	• Perimeter offices • Tiered standards	• Inboard offices • Functionally-based standards	• Smaller, fewer offices • Compact, universally sized standards	• Few multi-functional offices • No set standards • No predetermined worksta-tion- nomadic
Activity spaces:	• Large, formal	• Mix of formal and informal	• Variety of spaces, more small	• Accessible, flexible
Attributes:	• Structured • Linear • Independent	• Accessible • Inclusive • Transparent	• Streamlined • Collaborative • Energetic	• Adjustable • Social • Diverse/Improvisational

80% primary 20% activity	70% primary 30% activity	60% primary 40% activity	Blurred lines between Primary and activity

Figure 9: Key features and characteristics of the evolution of the office space - adapted from Rockwell Unscripted - https://www.knoll.com

Is it possible to design office space that uses different lighting conditions and that allows its users to select their environment based on lighting preference?

A brief review of the evolution of office layouts will help situate this paper and underline the importance of the proposed approach (figure 9).

1900s – The Taylorist Office (Perimeter): The American engineer Frederick Taylor is credited as being one of the first people to ever design an office space. Taylor was obsessed with efficiency and designed an office plan with striking similarities to a factory, high ceilings and large windows illuminated a large open-plan where workers were crowded together while upper management worked in upper private offices (figure 10). This layout had not been seen before and brought organization to the workplace while allowing office workers to be located away from the factory – in urban centers. However, telephones and typewriters were noisy and the crowded open area provided no privacy.

1950s – Corporate America: In the 1950s offices successfully became autonomous from their exterior environment. The steel and glass architecture of the modern movement was increasingly used, and a number of these glass buildings were built in New York, Montreal, and Toronto (figure 11). The increasing availability of fluorescent lighting and air conditioning meant that natural light and being near an open window were no longer seen as necessary, instead suspended ceilings controlled temperature and light levels.

1960s – The Office Landscape (Core): which translates from the German concept Bürolandschaft (figure 12). Bürolandschaft intended to dissolve the corporate hierarchies and moved towards social layouts that encouraged communication and collaboration within the workplace. There was no structure or fixed positioning of furniture, there were a diverse number of functions of an office environment, different layouts can be used for different functions. Also, there was no way for the employees to change things like the temperature or light to their own preference.

1980s – The Cubicle Farms (Efficient): The efficient office were open-spaces divided by modular partitions (figure 13). These partitions were high enough to blocked out distraction from colleagues and provide privacy, but they also blocked out exterior views and natural light. With less distractions – only a computer screen and fabric walls – it was claimed that workers were more productive. This was a bleak period for office design in which directors and managers had less interest in their workers' well-being and more about their profitability.

2010s – The Nomadic Office (Adaptive): advancement in technologies such as mobile devices and cloud storage mean that workplace has become much more flexible, information can be accessed from anywhere, the employees are not fixed to one workstation, and they can move around the office. The idea of the nomadic office is becoming increasingly popular within contemporary architecture.

Work places often provide a mixture of open plan areas and partitioned areas, and allow employees to move at their discretion. Furthermore, contemporary offices are offering additional amenities such as fitness sessions, lounge areas and even relaxation spaces (figure 13). Therefore it becomes possible to design office spaces in which the user can experience through a range of dynamic lighting conditions. Employees can move through spaces on a regular basis in order to experience light in different ways. By choosing their environment, they are given the opportunity to move in and out of light as desired (figure 14).

Commentary - Adaptive Workspace

The author collaborated on an adaptive (contemporary) office design in 2015. The office tailored spaces for all types of activities and all types of employees in a multidisciplinary office, with services ranging from accounting to creative and IT development. The design focused on providing its employees with a nomadic and activity-based work experience. Such offerings included various workstations, i.e., treadmill stations, 'work with a view', temporary meeting spaces, phone booths, communal work areas and reserved desks. In addition, the workplace provided communal and social spaces, including several lounges, cafes and bistros, an outdoor green space, a wellness center that included fitness facilities with changing rooms, and a reflection space. The final work environment offered more than 18 types of workspaces.

The challenge with an adaptive office space is that there are different environments and functions behind the same non-descriptive curtain wall and with the same consistent daylight conditions. What does the curtain wall do to the space where people work? It is a loss of an opportunity to create a different aesthetic impression by altering or controlling the way in which natural light enters a space. This would result in an adaptive workspace where people can move in and out of spaces with different lighting depending on what they need.

How do we use multi-layered envelope construction to create and accentuate the experience of working and living beyond the curtain wall? This research suggests that this can be done through the design of openings and envelopes that permit daylight to enter in a controlled and meaningful way. Here is a space where multiple functions can use changing lighting conditions and the users can select the light in their environment by moving through the space and experiencing light in different ways.

Concluding remarks

In an adaptive office environment, the potential exists to have different lighting conditions and light effects that accentuate the working experience within the environment. Thus, the author was inspired to study the spaces where people usually spend most of their time: the workplace, specifically, commercial office buildings. The flexibility of the work environment allows users to select their desired lighting conditions, moving toward or away from daylight and working under contrasting or uniform light. These luminous effects can create more stimulating and expressive office environments.

Figure 10: Office space of the 1920s. Source: https://en.wikipedia.org/wiki/Newsroom

Figure 11: Seagram Building New York City 1958. Source: https://en.wikipedia.org/wiki/Seagram_Building

Figure 12: Office landscape (Bürolandschaft) of the 1960s. Source www.gettyimages.com/photos/1960's-office

Figure 13: WeWork, Communal office workspace. Source: https://www.wework.com/

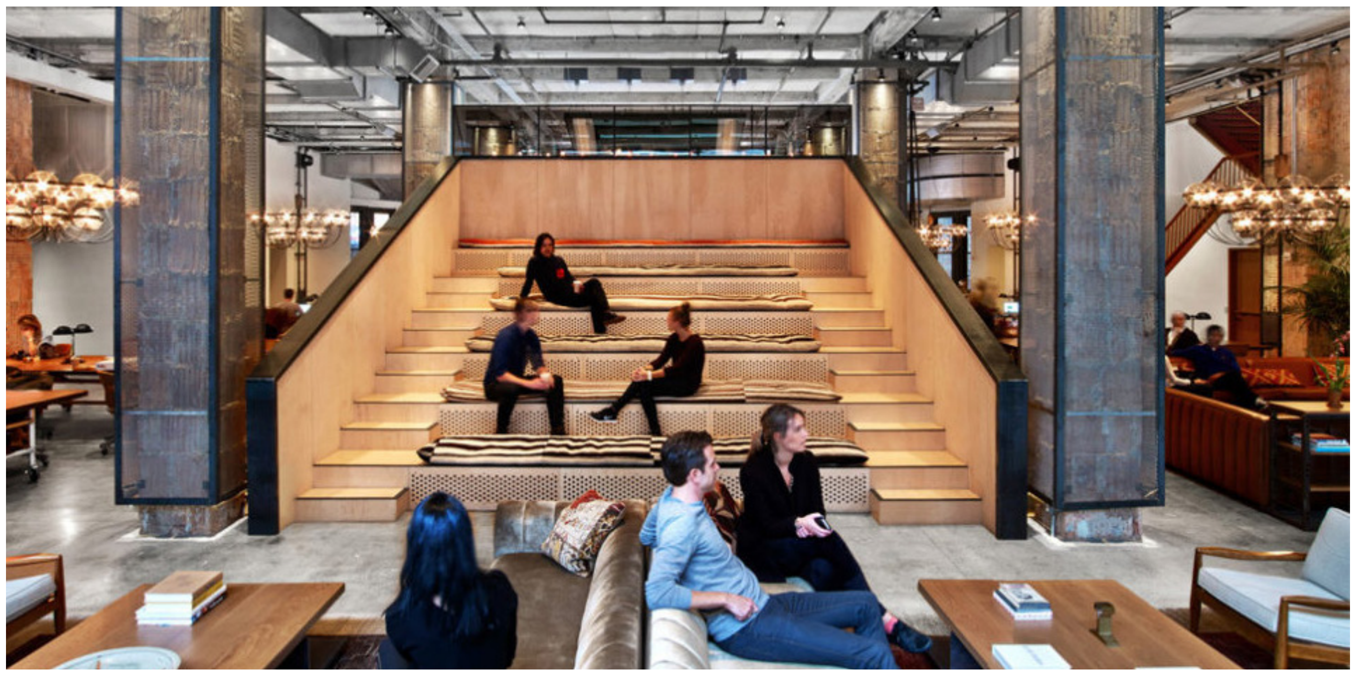


Figure 14: Neuehouse NYC co-working space designed by David Rockwell Photograph by Eric Laignel.

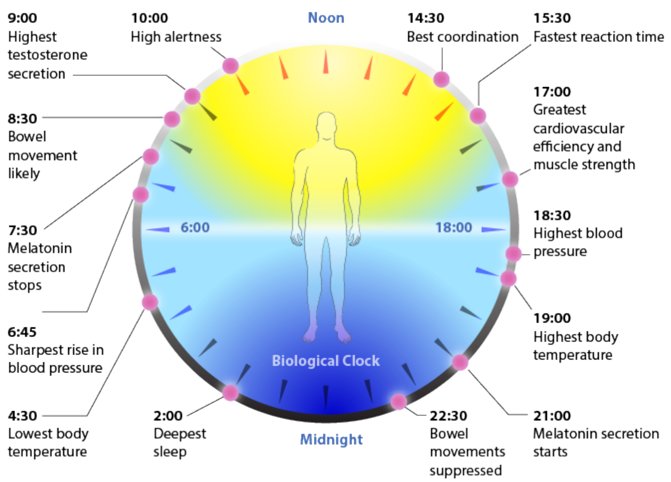


Figure 15: The human biological clock.
Source: https://healthstandards.org

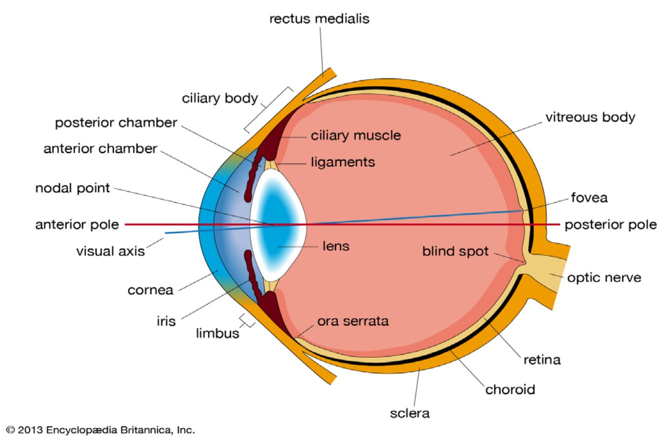


Figure 16: The Anatomy of the human eye.
Source: https://www.britannica.com/science/human-eye

Premise for Non-Visual Effects in Architecture – Health and Well-being

Light is an essential parameter for people to sense and perceive their environment. Light passes through the retina to specific neural and hormonal centers in the brain. Through evolution, human beings have adapted to the temporal character and full spectrum of natural light. The human eye is comprised of two classes of photo receptors: cones and rods. The human eye has about 7 million cones and 120 million rods (GSU, 2016). Cones are photopic and respond to high light levels (IESNA, 2011). Cones are located within the fovea – a small area in the center of the eye – and serve as bright light and color detectors but are not as useful in dark environments. Conversely, rods are scotopic and are more sensitive and respond to low levels of light. Depending on the amount of light entering the retina, one kind of photo receptors will become more responsive, while the other will deactivate. Changes in light levels are capable of exciting the human retina and creating a visual sensation (IESNA, 2011). A vibrant environment stimulates the visual system as both the cones and rods adjust to different illumination levels. Since cones are colour receptors while rods sense light and dark, we perceive light and shadow more vividly in lower light levels as there is less information (colour) to distract from the essential experience of light and shadow. However, typical illumination levels inside today's buildings are too high and uniform that the full capacity of vision is suppressed, the pupil innately contracts. The effects of light and shadow stimulate our vision and thereby influences our visual perception and experience of an architectural space.

In addition to stimulating visual response, daylight can also induce non-visual response, affecting our health and well-being (Boubekri, 2008). Extensive research published by Professor Mohammad Boubekri[1] from the Illinois School of Architecture indicates a link between natural light and biological systems. Human's circadian clocks have adapted to the cycles and spectrum of natural light (figure 15). Our systems are mediated primarily via a novel non-rod, non-cone photo-receptor, which exhibits different sensitivity to the intensity, spectrum, duration/pattern, timing and history of exposure as compared to visual responses (Lockley, 2009). This novel photo-receptor – the intrinsically photosensitive retinal ganglion cell (ipRGC) – has led to consideration of the non-visual effects of light as a vital component of lighting design. Daylight activates hormonal distributions, which affects our mood and energy level. Endocrine systems regulate hormonal levels that manufacture melatonin. Melatonin imbalances may cause irregularities in circadian rhythms and leads to sleeping disorders. Adequate exposure to natural light also provides vitamin D through a photochemical reaction that prevents Seasonal Affective Disorder (SAD). Seasonal affective disorder is a well-known consequence of insufficient daylight exposure and a disturbance of the serotonin/melatonin cycle (Webb, 2006).

1 Professor Mohammad Boubekri's work focuses on sustainable architecture and the intersection of the built environment and human health. Through numerous publications, a recently published book and a second book currently under review, he explores the impact of the lack of daylight inside buildings on people's health, behavior and overall well-being. More generally, his work also examines the relationship between architectural design, sustainable technologies and building energy/environmental performance. His teaching has encompassed such areas as building illumination, architectural acoustics, building economics, daylighting design, energy and building performance.

Research also links natural light to a boost in concentration that improves scholastic and task performance. Studies on health and natural light have indicated Attention Deficit Disorder (ADD) can be a cause of insufficient natural light within buildings (Boubekri, 2008). As a result, students with adequate exposure to natural light tend to perform better scholastically (Boubekri, 2008). Natural light also stimulates prod uctivity and enhances employee morale, thereby reducing absenteeism, preventing Sick Building Syndromes (SBS). Similarly, research by the Heschong Mahone Group[1] indicates that retail stores that introduce natural light by skylights may benefit from an increase in sales. Although the associated benefits of natural light are difficult to quantify, the general conclusion of this body of research is that natural light influences our experience of an architectural space, and illumination levels are important for visual task performance.

Figure 17: Manassas Park Elementary School illuminated by light louvers and elevated ceiling.
Source: https://en.wikipedia.org/wiki/Elementary_school_(United_States)

1 The Heschong Mahone Group, Inc. (HMG) provides professional consulting services in the field of building energy efficiency. They specialize in applying their knowledge of building design, construction technology, policy development and program design to the problem of making buildings more energy efficient.

Figure 18 Myyrmäki Church, Finland (1984) by Juha Leiviskä. Source: Plummer H. 2009.
Over the course of a day, natural light perceptually transforms the volume of the space. The top left image gives the perception of depth because of the illumination in the distance. The pews are also indirectly illuminated, creating layers of light. In the upper right image, the foreground is in shadow while the background is drawing towards us flattening the space but drawing the eye upwards above the altar. Light strongly brings in the elements of the sky and reveals the structure that is not immediately visible. There is a vertical expression of exultations in the vertical lines of light and shadow cast be the structure above. The hanging banners brought into light also accentuates the verticality of the space. the area in the far distance is illuminated with a dark foreground; it creates the impression of a much longer processional. In the lower right image, the foreground light is much more soothing and calming.

Premise for Visual Effects in Architecture – Light and Shadow

Natural light is one of the most influential elements of architecture. It possesses an unparalleled ability to pervade the built environment, and in doing so, it greatly affects how we perceive and experience our environment. It allows us to see, experience and perceive space, material, textures, and experience architecture under ephemeral conditions unique to location and time.

Light and shadow help architects to communicate their aesthetic objectives more comprehensively and choreograph the dynamic visual effects of space to meet their intended design goals. In his book Experiencing Architecture (1959), architect Steen Eiler Rasmussen writes about how the creative control of light can add deeper sensations to the built environment, he stated that "Light is of decisive importance in experiencing architecture. The same room can be made to give very different spacial impressions by the simple expedient of changing the size and location of its openings" (Rasmussen, 1964, p. 187) (figure 18). Light not only has the power to transform experience, but it also brings a person to full awareness of their surroundings. Finnish architect Juhani Pallasmaaa discusses this idea in The Eyes of the Skin. In his book he reminds us that "Light plays a crucial role to aid us in becoming fully conscious of our existence in the world, and provokes interaction at an immediate, visceral and pre-cognitive level with the light we encounter" (Pallasmaa, 2012). Moreover, the German philosopher Edmund Husserl observed that by suspending our understanding of place and encountering the space with primal instincts, it becomes possible to heighten our experience of place through aspects of light we may not have consciously noticed.

Successful awareness of space is heighted through the interplay of light and shadow. Light and shadow draws our attention towards spatial complexities and highlights areas of material transitions while the dynamic nature of sunlight generates various luminous effects over time. Two dimensions that are widely accepted to influence our perception of space are average luminance and luminance diversity (Cetegen, 2008). The former has been directly associated with perceived lightness and the latter with visual interest. The human vision is stimulated and heightened when confronted with both light and shadow, elevating how we perceive and sense the built environment (Holl, 2007).

Figure 19: Grand Central Station. Hal Morey's famous 1943 photograph of sunlight streaming through the windows of Grand Central Station, New York (1914) is one of the most ubiquitous images of light and architecture in the twentieth century, image courtesy of https://en.wikipedia.org

Architectural Openings

> *"As light passes through small holes, it spreads out, frays and bends. The resulting shadows do not necessarily look like the silhouettes of the objects that cast them. Light bends in ways that yields shadows with bright bands, dark bands, or no sharp edges."* (Holl, 2006, p. 107)

Architectural devices and forms, i.e. openings, doors, windows, and screens, manipulate and control how daylight is introduced into a building. The design, orientation, scale and position of these openings control when and how light enters. Careful thought to the design of an opening can lead to impressive, intended, and even unanticipated effects that contribute to the spatial experience, the experience of which is uplifting, stimulating, and appealing.

The various attributes of an aperture can have assorted impacts on the quality, intensity, and diffusion of natural light. For example, are there significant differences in the lighting effects of an opening that is circular versus square? Will different parameters control daylight in a way that will affect the spatial perception of a space, accentuate volume or a surface? What feeling is generated when natural light is introduced from below or from above? How is the concentration or diffusion of natural light affected by the design of an aperture? Finally, how can architecture use this information to give spaces meaning, to define spatial boundaries, to accentuate volumes and form, to stimulate the built environment? When designing with light, these questions must be asked and studied to determine how a room or space will appear and feel, and thinking of these questions when designing spaces is essential to create meaningful experiences and subsequent perception of space.

By studying how various apertures control and manipulate light, we may determine how they can generate desired effects. These effects can be used to enhance the perception of the spaces we occupy. For example, one concept is to use controlled light to create spaces that perpetually change with the flows of nature, both climate and time, thereby generating individualistic experiences varying from the single moment the space is encountered. It may be desired to cast direct light on a station platform or office building entrance every morning at a particular hour and thereby generating a moment of joy and connection in the routine of the people passing through the space every day (figure 19). In this case, it would be valuable to study how dynamic and sensitive lighting conditions can be generated to enhance the desired connection between the changing exterior conditions and the interior lighting. Another concept may be to design a procession of spaces with ranging lighting conditions that relate to the intended function of a space. This can then be used to create different perceptions of space leading to heightened experiences or allowing occupants to travel through a range of stimulating perceptual conditions (figure 20).

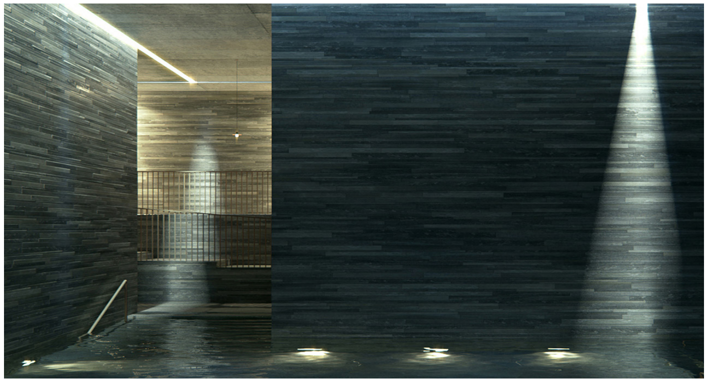


Figure 20: Therme Vals (1996) by Peter Zumthor is a spa which combines a complete sensory experience. Users enjoy the water not only at various temperatures, but in different spaces and conditions: in light, darkness, and twilight, or standing in shadow looking to the bright colourful landscape. Sunlight trickles in through narrow slits or through gaps left open between the stone slabs of the ceiling. The combinations of light and shade, open and enclosed spaces and linear elements make for a highly sensuous and restorative experience.
Source: https://en.wikipedia.org

Method

For this experiment, the author modeled 32 studio spaces that display a range in lighting conditions. Each space is identical except for the properties of the opening(s) that deliver light.

The experimental objectives presented in this paper are three-fold: 1) to measure the impact of lighting conditions generated by a variety of architectural openings, 2) to evaluate the luminous effects on subjective ratings of aesthetic impressions, 3) to determine if there exists a correlation between the lighting conditions and the aesthetic impressions. The first objective is to explore how light can be controlled by various opening attributes. The second objective relies on subjective surveys to explore the relationship between photometric measurements taken and the perceived impressions of an interior space. The final objective is to use the information to predict lighting aesthetics and performance for a specific building type and spatial function. To accomplish this, a communal workspace office building will be studied and designed to demonstrate how architecture can achieve both adequate and pleasant illumination within a built environment.

Architectural Space

The term aperture[1] will be used throughout the duration of the experiments to categorize the various types of openings used to deliver light within an interior space, horizontal or vertical windows, skylights, perforated openings, or architectural forms.

The attributes of an aperture affect the intensity and diffusion of light within a space and thereby influencing the appearance and perception of a space. These conditions can contribute to the selection and design of architectural forms and openings to create desired appearance and spatial expression. Light through these openings become visible by the projections of light and shadow generated on the surfaces within the space. These patterns and projections are animated features resulting from the design of an aperture.

1 Oxford dictionary defines aperture as:
1. An opening, hole, or gap.
1.1. A space through which light passes in an optical or photographic instrument, especially the variable opening by which light enters a camera.
In the context of this paper the author is using the term aperture to represent any architectural opening that permits light to enter an enclosed space.

To further explore the relationship of apertures and the control of natural light, experiments need to be designed to demonstrate the architectural effects that may be produced. The experiments need to be able to compare the different conditions generated. A constructed model allows us to evaluate natural light introduced into a fixed space. By altering the aperture of the model, various light conditions can be documented. This technique of observing lighting conditions and patterns relates back to the discoveries of light in the camera obscura, where refracted light passing through a convex lens is reflected on a surface, which then was observed and painted. The model box allows the experiments to examine the effects of natural light on an interior space in a particular and controlled way. The models can be scaled, stacked, or arrayed into the design of a building.

Results from the experiment must be documented to successfully, and conclusively evaluate the conditions generated by various apertures within the model box. Observation from an oblique section provides valuable information about how light is distributed in the experimental space. An oblique section simulates how we would experience this space and reveals how light will project on multiple surfaces and what are the effects. This is important to observe the patterns and diffusion of light on the surrounding planes – walls, ceilings, and floor. Any additional parameters may not provide additional information because the experiment will be symmetrical, and to simplify the focus of the experiment, it shall be limited to this reference point. The illumination levels will be measured along the floor plane with a light meter and then documented and graphed to compare intensity and distribution. Plotting the ranges of illumination over the oblique section will give insight as to how each aperture controls light.

The analysis of the documented data and graphs should demonstrate the different conditions generated by each aperture. A comparison of the images will also give insight as to the appearance and effects generated by the light intensity and distribution, arguably resulting in some designs that are more interesting and expressive than others. The intention is not to determine if one solution is better than another, but comparing the effects and possible expressions that may result. This comparison may assist in choosing how to control light to create a desired appearance and effect for a particular architectural space.

Results

Refer to part *06 Experiment Results* for the complete set of experiments and results.

The experiments in part *06 Experiment Results* demonstrate a comprehensive range of architectural examples of how natural light impacts our spatial perception through the design of various apertures. Observations illustrated the luminous effects (light and shadow) from an occupants' perspective. These experiments seek to expand our understanding of how to create specific effects with natural light. In order to rank these perceptual effects, the experiments used comparative examples to illustrate how variations of a design of an aperture will impact these luminous effects (light and shadow).

The quality, intensity, and diffusion of light varied depending on how light was introduced into the model box. Some experiments demonstrated highly vibrant patterns of light and shadow that seemed to animate on the surrounding surfaces, as shown in the apertures of experiment 2. In these experiments the openings were arrayed creating fragmented areas of light and shadow. In other conditions light was focused into the box, creating contrast and sharp shadows as shown in experiment 1A apertures 05 to 08.

Our perception of space is determined by the parameters of an aperture. The volume of each experiment is identical, yet how light is introduced can alter our perception of depth, as shown with apertures 05 and 06 of experiment 1A. By locating the opening at the ceiling plane, the volume appeared taller than when the opening was near the ground plane. Conversely, the volume appeared deeper with the opening at the ground, illustrating how the control of light can influence the volumetric perception of a space. This may be used to control aspects of the built environment such as accentuating the height of an atrium or enlarging narrow corridors.

In Experiment 1A, the square and circular apertures revealed something interesting. It would have been safe to assume that these two apertures would have diffused light in a similar way given that the areas of their openings are the same. However, the experiments demonstrated that the light intensity and contrast changed by the attributes of the opening. The square opening permitted more natural light and resulted in a higher contrast, while the circular opening resulted in softer shadows. As a result, our perception of each space is different; the circular opening was perceived more calming while the stronger contrast of the square opening was perceived more stimulating. The interior space was also perceived more confining in the circular experiment. Contrast can be used to control the level of excitement of a space, ranging from calming and sedative to exciting and stimulating. This is an important characteristic to consider when defining the function of a space and the desired perception.

The experiments illustrated that different apertures not only resulted in different lighting intensities but also in different luminous effects of light and shadow. The apertures of Experiment 2 demonstrated these effects by the patterns projected on the interior surfaces. These patterns were subjected to the perpetual qualities of natural light and the exterior conditions. Over the course of a day, seasons, and weather conditions the characteristics of light varied and thereby altered the intensity, hue, and orientation of these patterns which reinforced the connection with the natural environment. Different apertures heightened this connection more than others as shown with apertures 01 to 04 of experiment 2. These apertures can be used to register changes in light, perceptually transforming the interior space to reflect the outside conditions. Spaces that reflect the changes in daylight fulfill human's innate need to be connected with the natural environment.

Qualitative Ranking

An empirical study of each experiment was conducted by 28 design and architectural professionals . This is not a statistical study; there is no factor of reliability, but an empirical validation to the author's perceptual observations. The participants were asked to fill out a semantic rating scale based on their perceptual interpretation of each experiment. Not all experiments were interpreted identically, to distinguish the range of responses the scale used two tones (black and grey) to plot the range of results. A solid black dot represented that the majority of the participants selected the same ranking. A solid grey dot represents that at least 20 percent selected this ranking.

The scale ranked the perceived level of contrast, uniformity, patterns, coherence, stimulation, and spaciousness observed for each experiment. The following semantic attributes were surveyed for each experiment result :

- **Contrast (Low Contrast – High Contrast)**
- **Uniformity (Uniform – Focused)**
- **Patterns (Subtle – Vibrant)**
- **Coherence (Simple – Complex)**
- **Stimulation (Calming– Stimulating)**
- **Spaciousness (Confined – Expanded)**

The author has created a list of 12 descriptors based on perceptual attributes that were observed in the experiments. These descriptors, although there may be more, are considered fundamental to the development of this thesis.

This analysis provided a qualitative ranking between a design of an aperture and a spatial experience. For example, ranking provided an indication of the spatial experience and characteristics of an environment that would result under similar lighting conditions – with a similar aperture. This information can be used to provide validation of how an interior space will be perceived. The data collected can be referenced to assist in the design of desired spatial experiences relating to the building or spatial function. This allows architects to carefully select and design openings to manipulate natural light with meaning, creating deliberate and wonderful effects for different activities based on the building program.

Conclusion

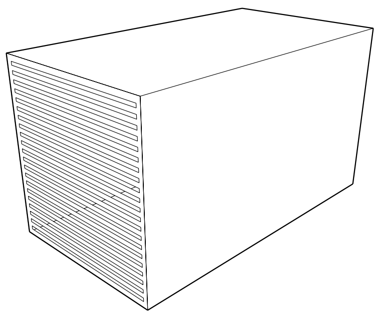
Natural light has a positive effect on our health and well-being. In addition, daylight provides an energy-efficient source of illumination. As a result, commercial buildings are designed to permit the most possible natural light. This is done through transparent building envelopes. The problem with full glass curtain walls is that they do not control natural light, and as a result light tends to be uniformly dispersed. Controlled natural light creates luminous compositions of light and shadow, which is both aesthetic and stimulating.

The evolution of the contemporary office allows for non-uniform lighting conditions. Users now have the mobility to select their work environment based on personal preference and visual task. In addition, the diversity of spatial functions of an adaptive office environment encourages different lighting conditions.

In conclusion, the experiment presented in this paper resulted in the following findings: 1) the attributes of an opening have a significant effect on the resulting lighting conditions (luminous compositions). The shape and location of an opening alter how light is distributed, the luminance variations, and intensity. These luminous compositions have a significant effect on subject ratings of contrast, uniformity, pattern, coherence, stimulation, and spaciousness. These visual effects seem to be good predictors of the spatial perception of a space, particularly the descriptors of coherence and stimulation. 2) The participants of the survey had somewhat consistent results; they preferred bright, non-uniformly lit environments with some luminance diversity. 3) By predicting how visually appealing a space may be, this study offers a new strategy for daylight design and performance. Rather than being satisfied with spaces that are adequately illuminated or tolerating overly bright spaces, this study evaluates humanistic visual appeal. Although photometric studies are necessary, other factors, such as those presented in this paper, also require our attention so that they may contribute to the design and aesthetics of daylit interior environments.

02. Light Qualities

The research of this paper surveyed 32 environments under a variety of lighting conditions. Each space was then evaluated based on the perceived level of contrast, uniformity, patterns, coherence, stimulation, and spaciousness. The spatial perception of each environment was then rated by 28 design and architectural professionals. These rantings determine the light quality derived by each opening. The following section organizes these spatial perceptions by the light qualities generated, ranging from high to low contrast, From the 32 conditions, 9 have been extrapolated and will be further explored herein. These 9 light qualities establishes a palette of that can be referred to by designers when selecting the type of façade to generate the desired illumination conditions for the intended spatial function. The palette ranges from Direct & Exaggerated to Indirect and Diffused.

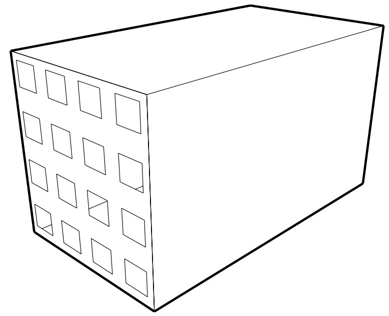


—1

Direct & Exaggerated

Direct & exaggerated lighting condition minimally obstructs direct light. The result is a pattern of high contrast and sharp shadows. Examples include Calatrava's Milwaukee museum, Foster's Kogard courtyard, and Ito's Serpentine Pavilion.

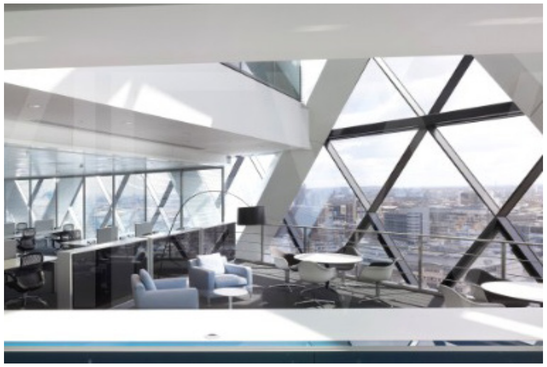
CALATRAVA MILWAUKEE ART MUSEUM



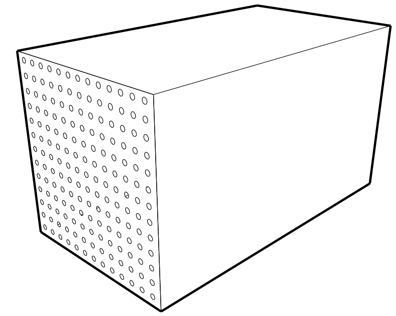
—2

Direct & Dramatic

Direct & dramatic lighting condition partially blocks direct light. The result is a pattern of soft shadows. Examples include Foster's Kogard Courtyard, Herzog & de Meuron's Prada Store, and Jean Nouvel's The Gherkin.



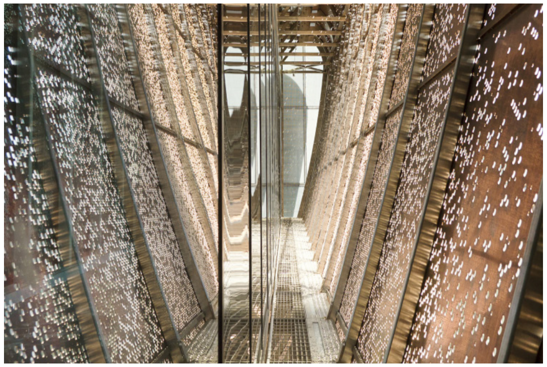
JEAN NOUVEL THE GHERKIN



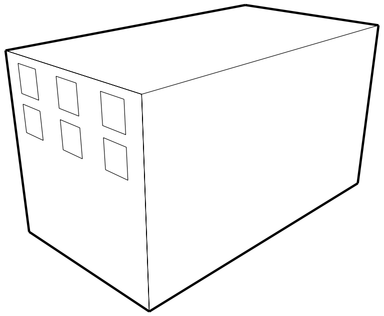
—3

Direct & Screened

Direct & Screened lighting condition partially permits direct light. The result is a pattern of fragmented light. Examples include Herzog & de Meuron Dominus Winery, Jean Nouvel's Arab World Institute, and Neuf's CHUM.



NEUF CENTRE HOSPITALIER DE L'UNIVERSITE DE MONTREAL

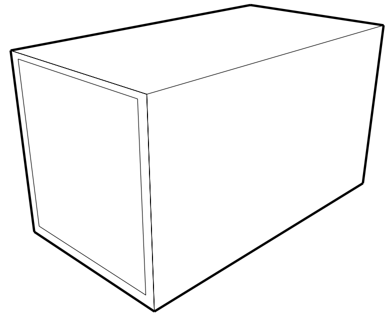


—4

Partially Direct

Partially Direct light screens a part of the direct light. The effect is a contrast of bright and screened light. Examples include William Rawn's Cambridge library, Glen Murcut's Flether house, and Manassas Park Elementary School

WILLIAM RAWN
CAMBRIDGE LIBRARY

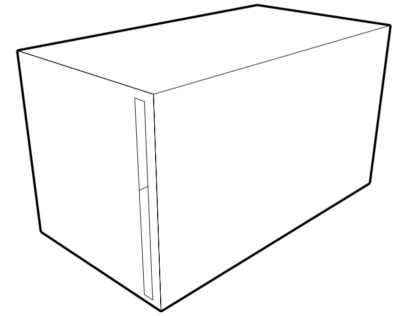


—5

Direct

Direct and unobstructed light through large openings. The lighting condition is non-articulate. Examples include Sanaa's Glass Pavilion, Bohlin Cywinski Jackson's Apple Store. and Mies van der Rohe's Farnsworth house.

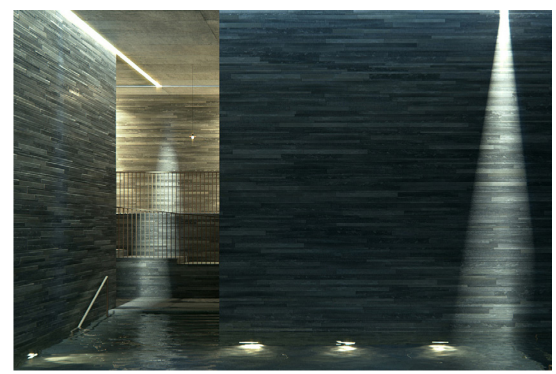
SANAA
GLASS PAVILION



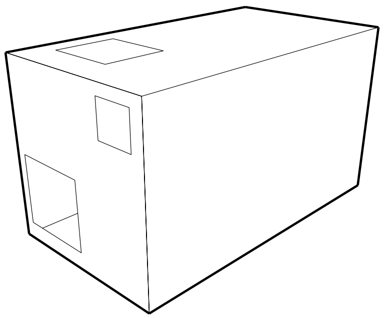
—6

Selectively Direct

Selectively Direct lighting condition permits directly light through a variety of openings. The effect is focused light at various location. Examples include Tadeo Ando's Church of Light, Libeskind's ROM, and Peter Zumthor's Therme vals.



PETER ZUMTHOR
THERME VALS

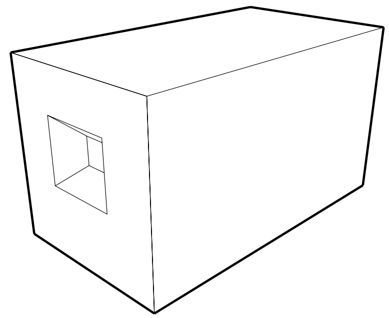


—7

Direct & Indirect

Direct & Indirect lighting conditions partially diffuses light by reflecting it off a surface. The result is focused and ambient lighting. Examples include Le Corbusier's Ronchamp, Alvar Siza's University of Santiago, and Holl's Sarphatistraat.

STEVEN HOLL
SARPHATISTRAAT OFFICES

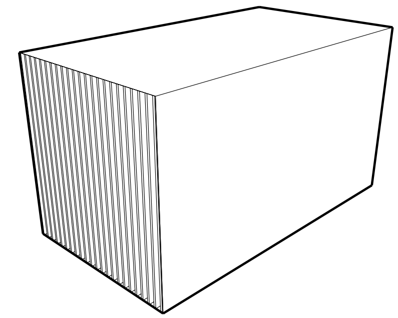


—8

Indirect

Indirect lighting conditions blocks direct light by reflecting it on a surface. The result is soft diffused light that enlarges a space. Examples include Foster's HK airport, Renzo Piano's High Museum, and Diller Scofido & Renfro's Broad Museum.

DILLER SCOFIDO & RENFRO
BROAD MUSEUM



—9

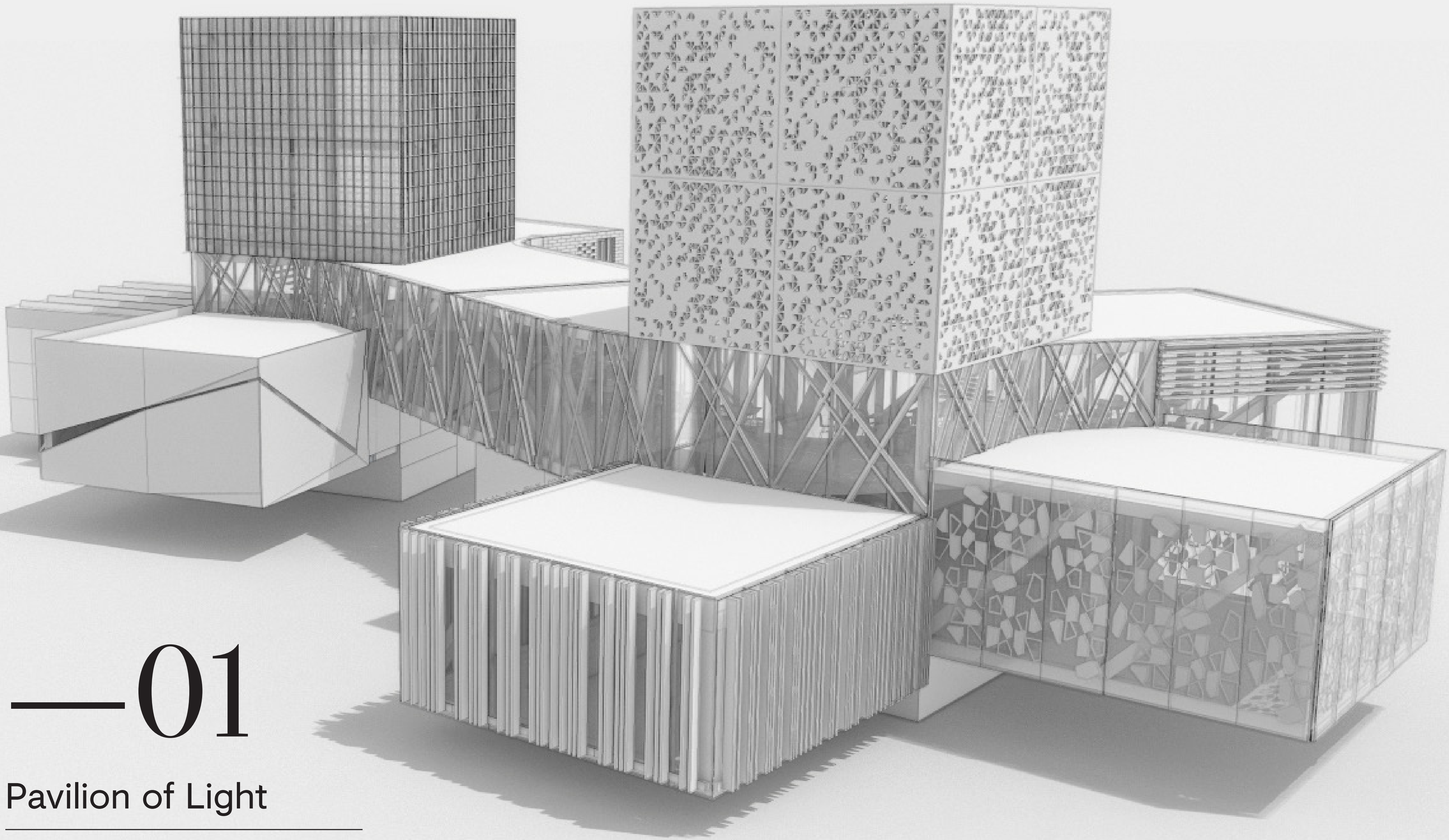
Indirect & Diffused

Indirect & Diffused lighting conditions blocks direct light by filtering it through a screen. The result is an ambient glow of illumination. Examples include Kundig's Shinsegae Offices, Shigeru Ban's Naked House, and Chareau's Maison de Verre.

PIERRE CHAREAU
MAISON DE VERRE

03. Light Pavilion

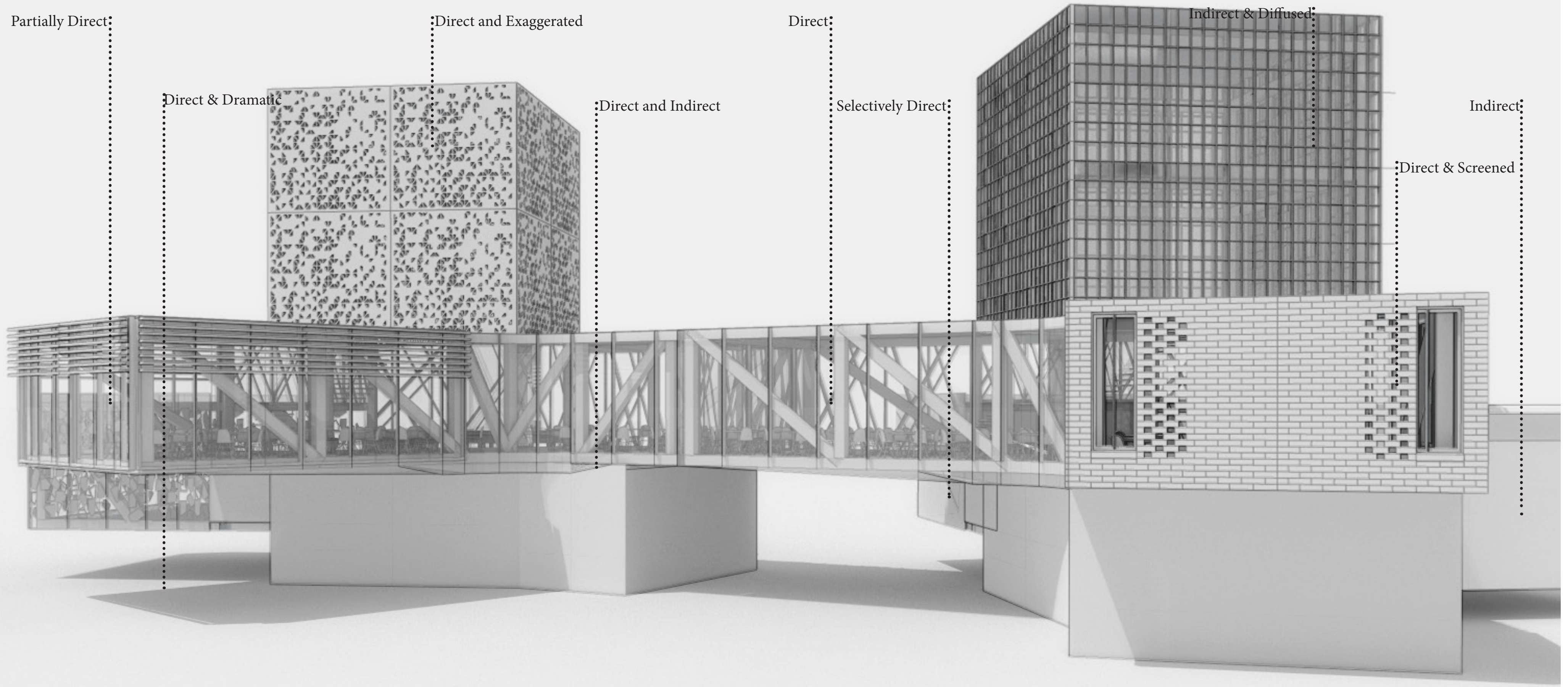
To successfully demonstrate how the various light qualities may be orchestrated together, a light pavilion was designed. This Light Pavilion demonstrates a series of 9 lighting characteristics that this thesis determined are important. The Pavilion will not consider specific spatial functions at this moment, but will evaluate orientation, location and time. A procession through the light pavilion will demonstrate the effects of each facade and their derived light qualities. We can travel through the space, and through a series of adjacent spaces, experiencing different spatial perceptions and experiences. The Pavilion is arranged with two wings defined by the light qualities at each of the spectrum, direct and exaggerated and indirect and diffused. These qualities can be configured to generate an order or comparison of adjacent conditions that can further assist in the program layout of the design project.



—01

Pavilion of Light

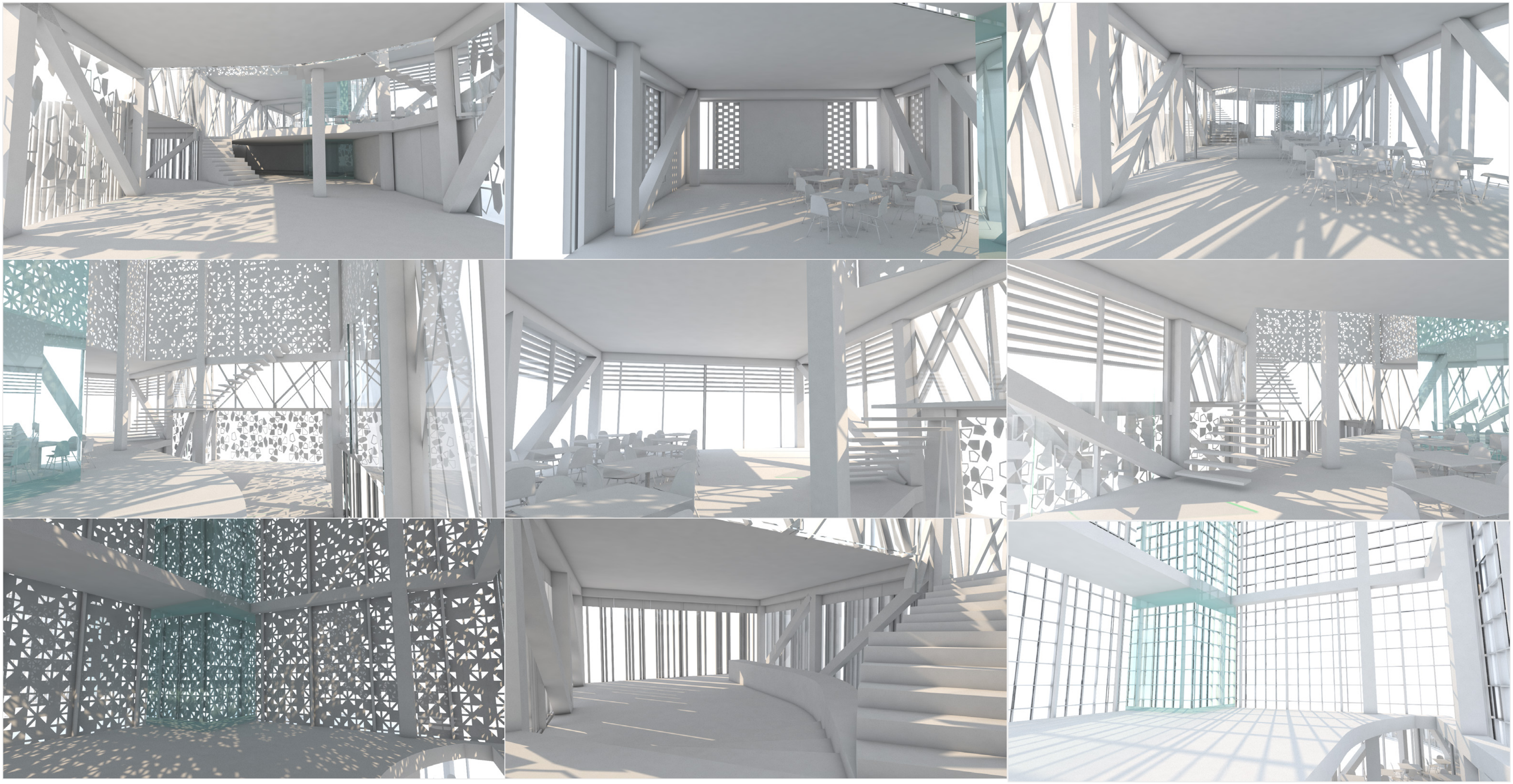
Direct and Indirect Halls



—02

Pavilion of Light

Bridge connecting Direct & Indirect Halls



A procession through the pavilions illustrating the perceptual and spatial experiences though the 9 light qualities.

—03

Pavilion of Light

Vignettes

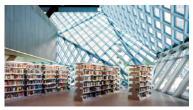
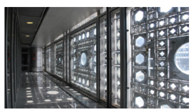
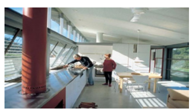
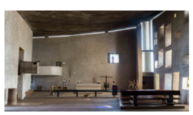
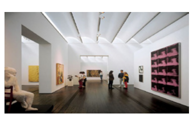
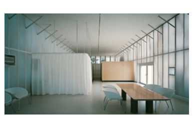
04. Design Intent

Speculative buildings tend to be illuminated by full glass curtain walls that offer little in terms of diversity of environmental experience. As a result, there is little emphasis towards the use of light to produce luminous effects and spatial qualities. The purpose of this research is to design a building that contains multiple illuminated environments to demonstrate the appeal of diversity in lighting practice. The proposal of a mixed-use building will be the foundation of a demonstration of improved lighting quality for a diverse urban environment.

Mixed Use Building Program

This matrix illustrates the spatial functions and the range of lighting qualities deemed appropriate for the activities and desired experience. Each spatial function can have more than one associated light quality, as well as several spatial functions can be grouped within the same light condition. The matrix serves as a design tool and reference when designing a specific space and selecting the quality of light and facade.

Lighting Qualities (HIGH CONTRAST / STIMULATING ↑ — ↓ LOW CONTRAST / CALMING)

Lighting Qualities		Lobby - Reception	Restaurant	Café / Bistro	Gallery / Exhibition	Apartments	Common Areas	Open Office	Meeting Rooms	Conference Rooms	Lounges	Fitness / Pool
DIRECT & EXAGGERATED		●	○	○	○	●	●	○	○	○	○	○
DIRECT & DRAMATIC		●	●	●	○	●	●	○	○	○	○	○
DIRECT & SCREENED		●	●	●	○	●	●	○	○	○	●	○
PARTIALLY DIRECT		●	●	●	○	●	●	○	●	○	●	○
DIRECT		○	●	●	○	●	●	○	●	○	●	○
SELECTIVELY DIRECT		○	○	●	○	●	●	○	●	●	●	●
DIRECT & INDIRECT		○	○	●	●	●	●	●	●	●	●	●
INDIRECT		○	○	○	●	○	●	●	●	●	○	●
INDIRECT & DIFFUSED		○	○	○	●	○	●	●	○	●	○	●

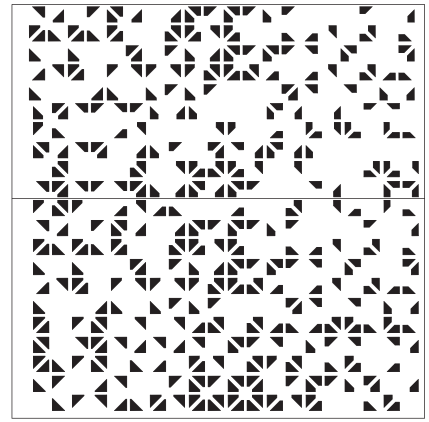
July 01 November 01 February 01

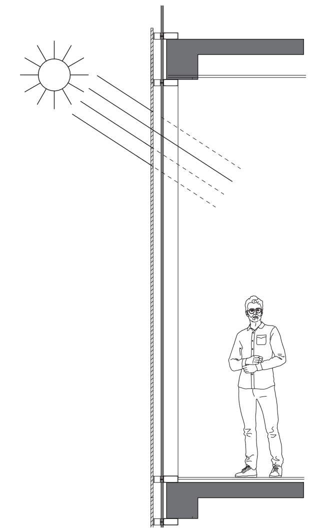
9am

12am

4pm

Location: Montréal Québec 45.5017° N, 73.5673° W
Building orientation: SW



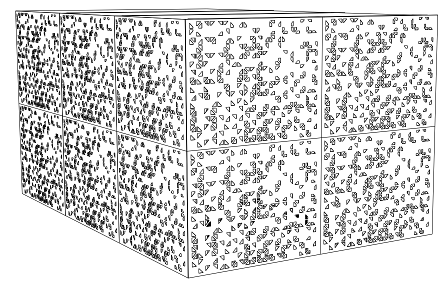


Elevation and Section

—1

Direct & Exaggerated

Lobby



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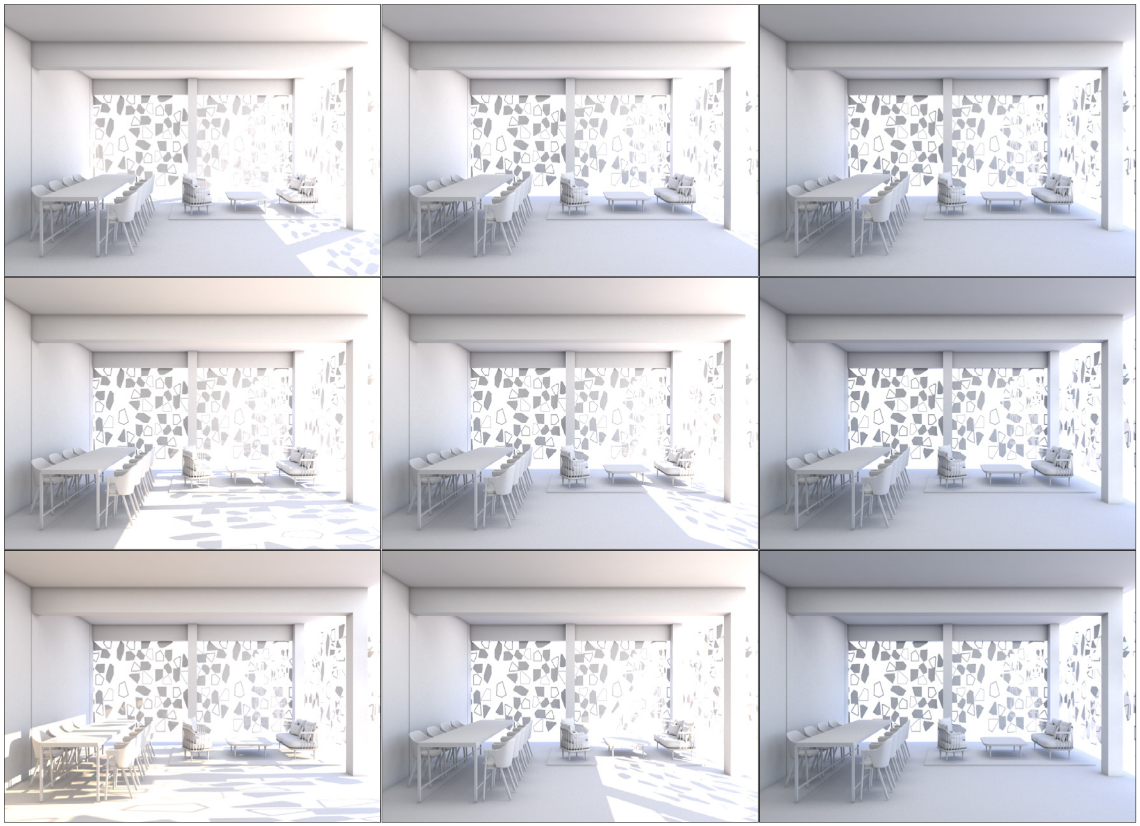

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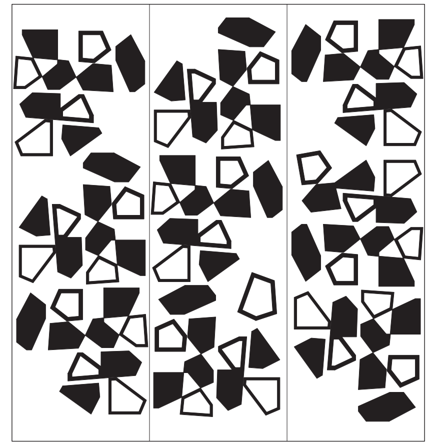
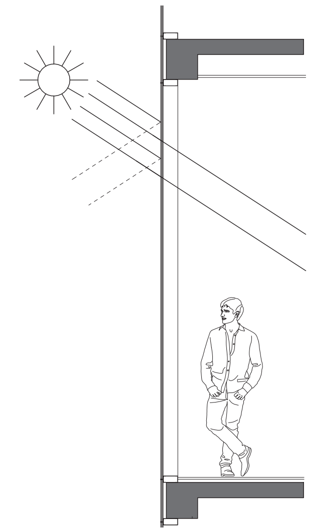
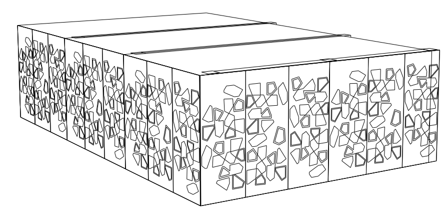




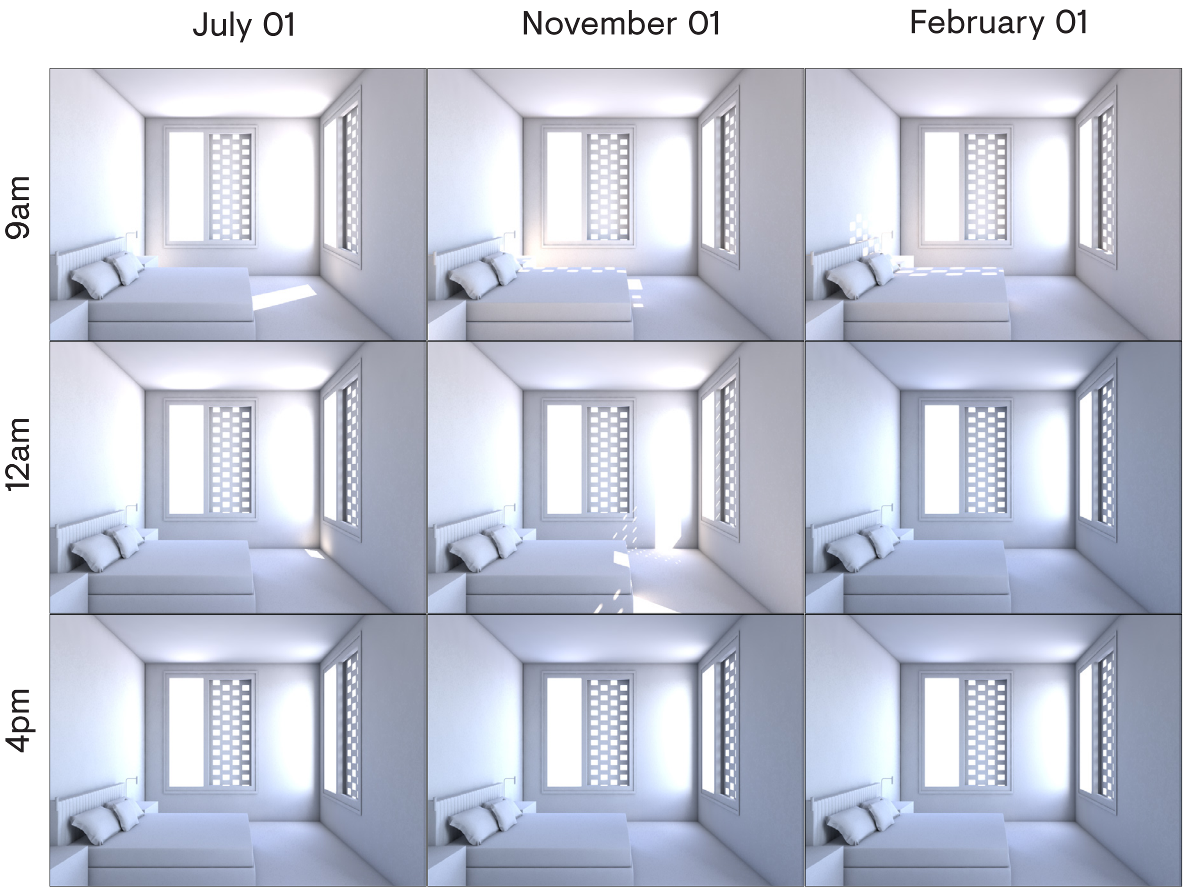
Elevation and Section



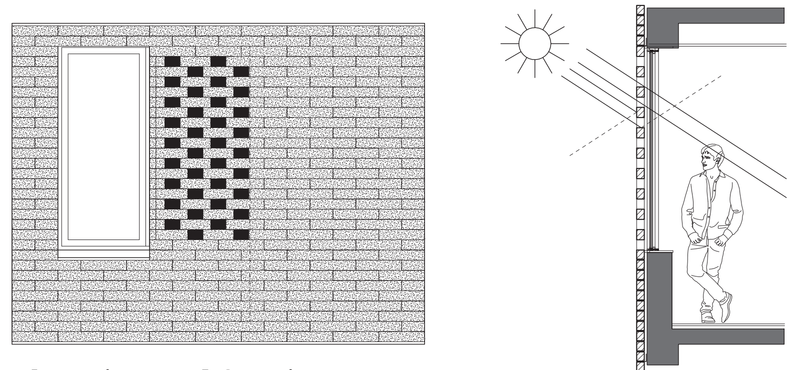
—2

Direct & Dramatic

Lobby



Location: Montréal Québec 45.5017° N, 73.5673° W
Building orientation: SW

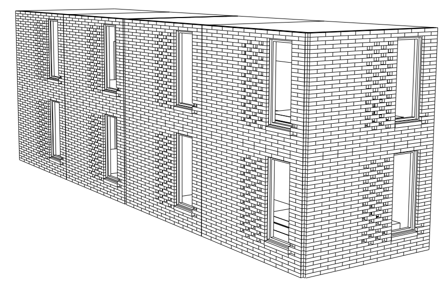


Elevation and Section

—3

Direct & Screened

Suites



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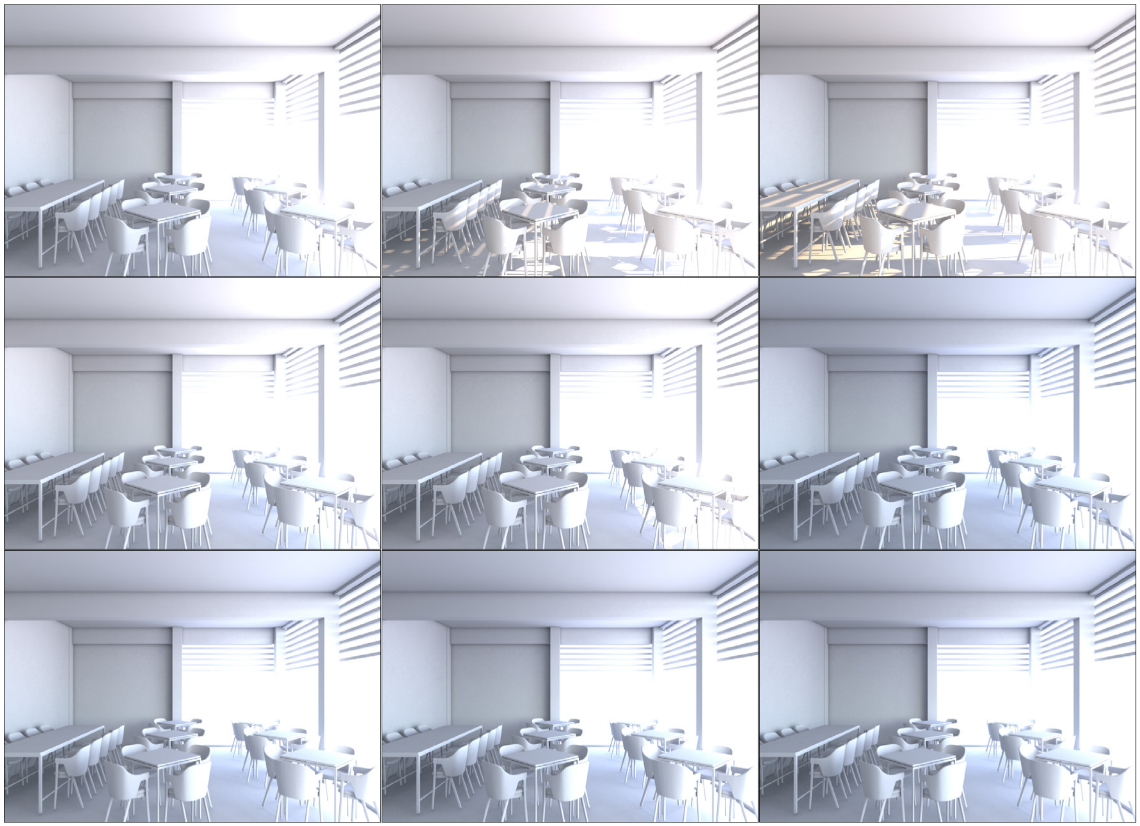

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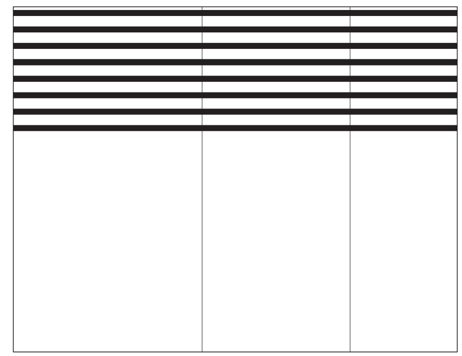
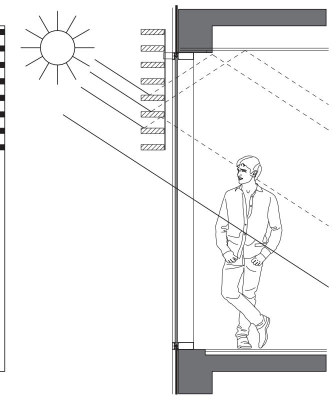
Building orientation: SW



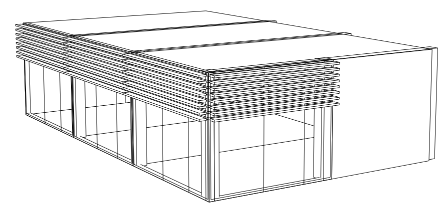


Elevation and Section

—4

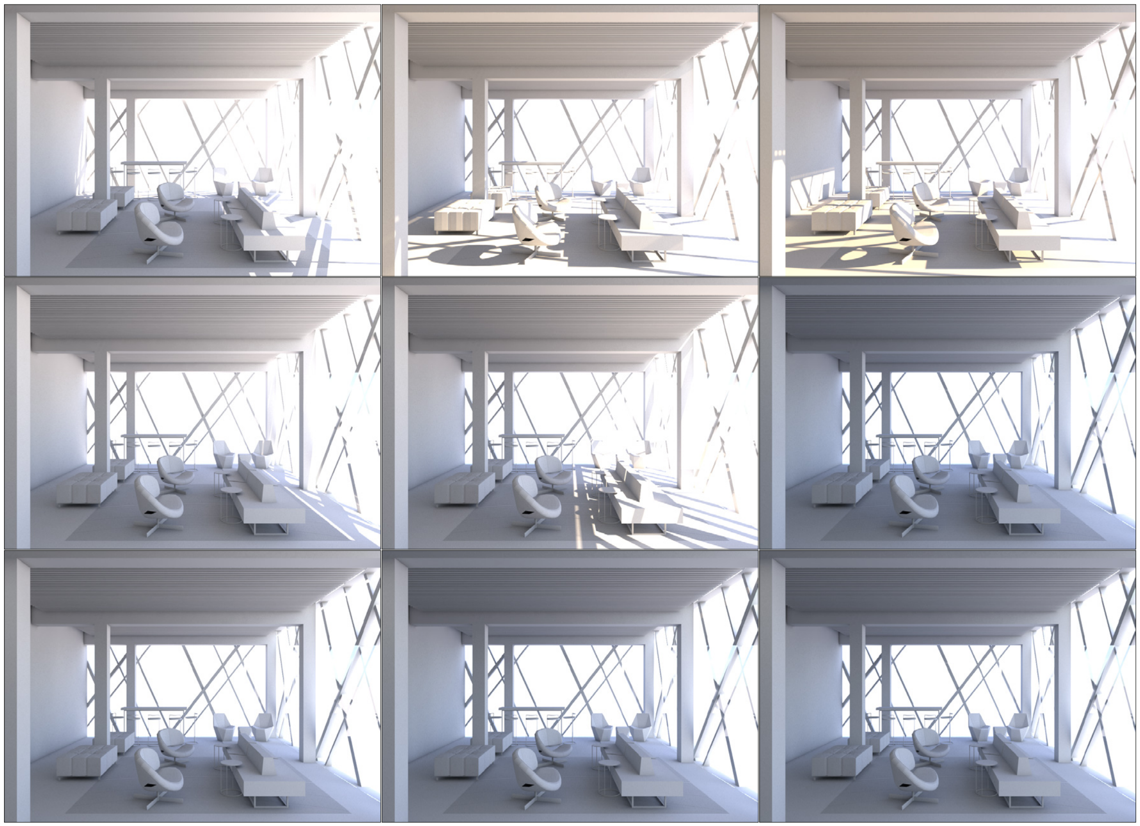
Partially Direct

Restaurant



July 01 | November 01 | February 01

9am / 12am / 4pm



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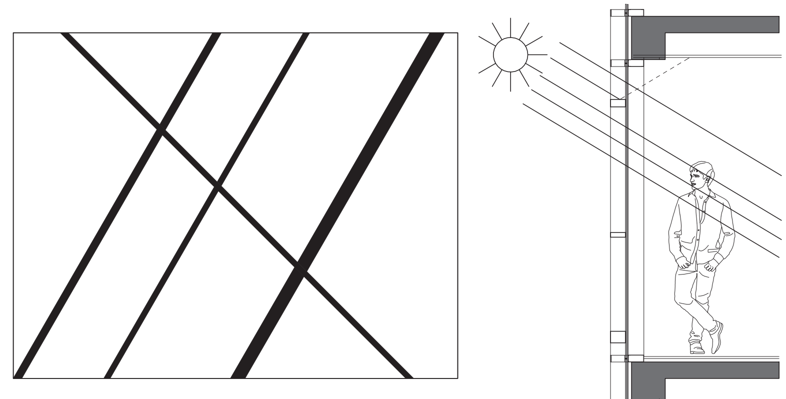
Building orientation: SW

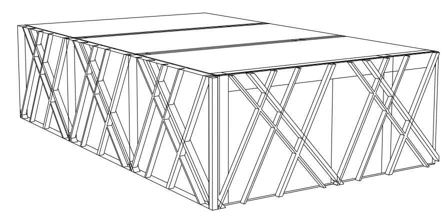


Elevation and Section

—5

Direct

Lounge / Common Space



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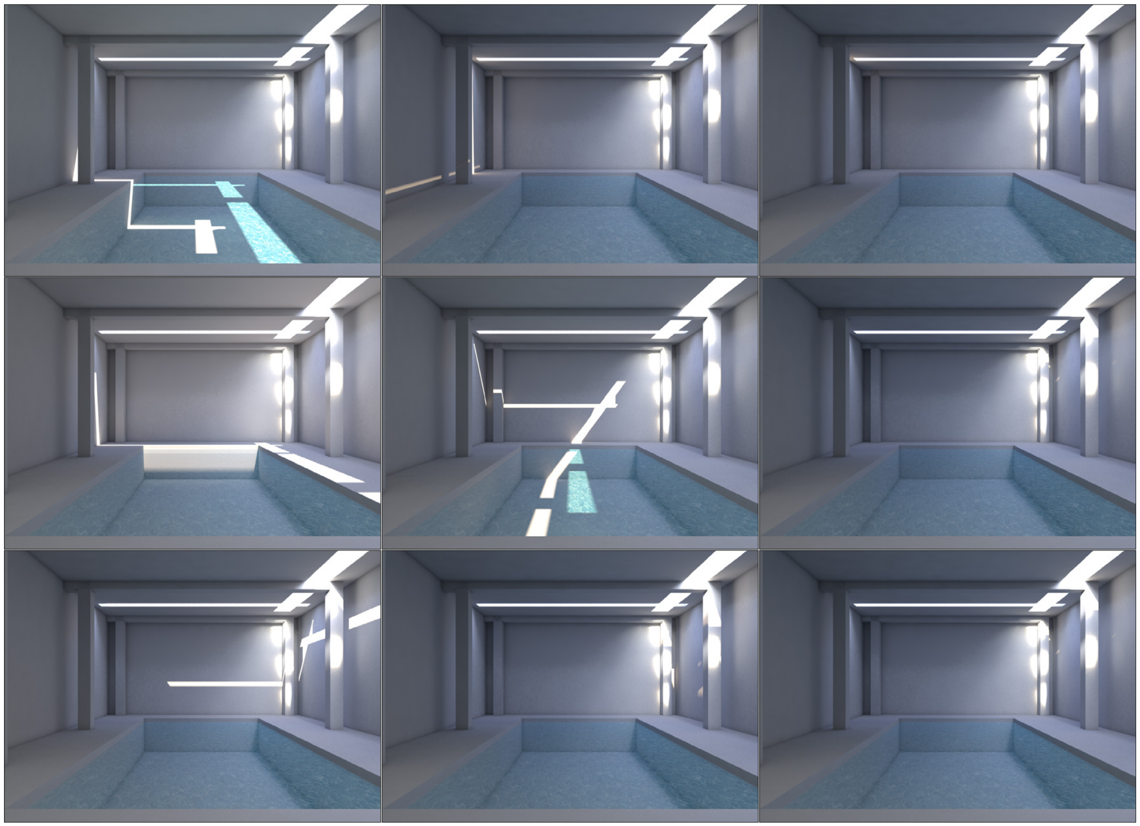


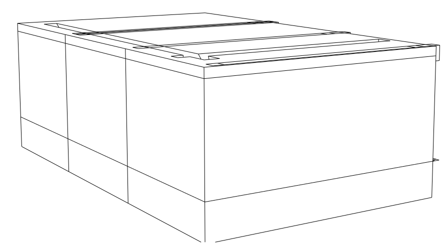
Location: Montréal Québec 45.5017° N, 73.5673° W
Building orientation: SW

Elevation and Section

—6

Selectively Direct

Pool / Fitness



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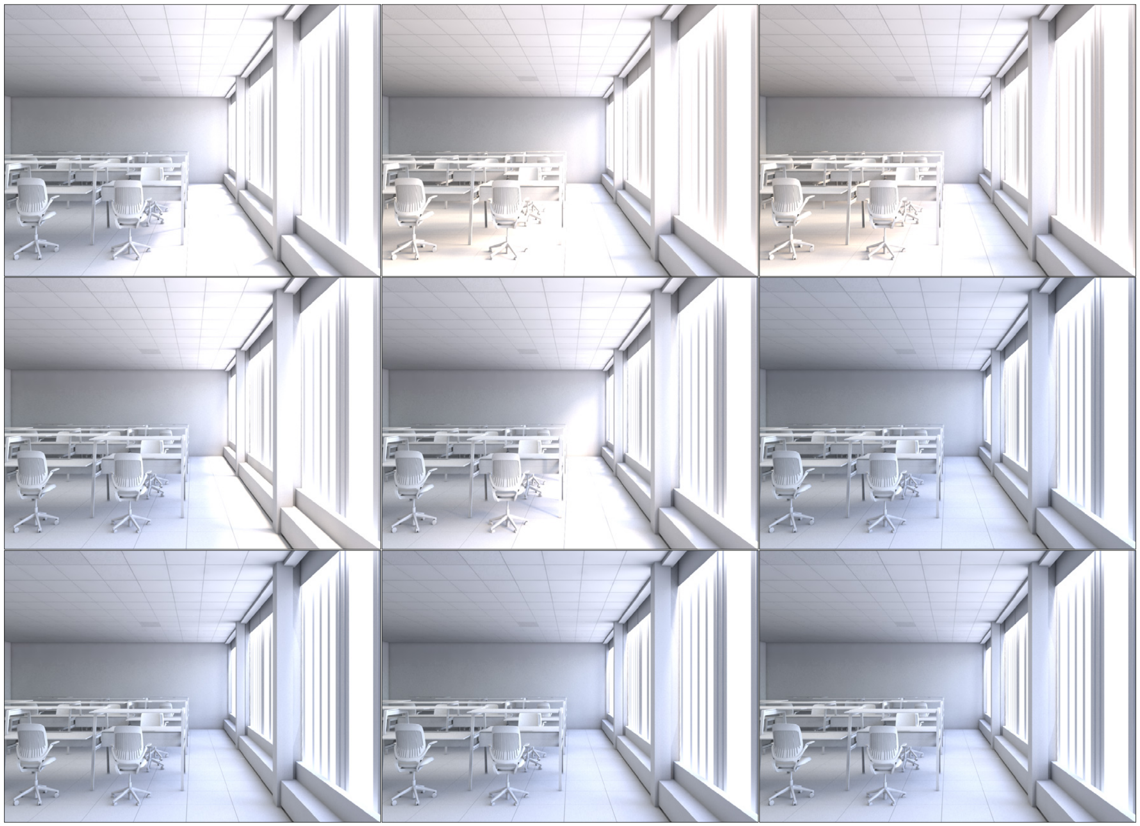

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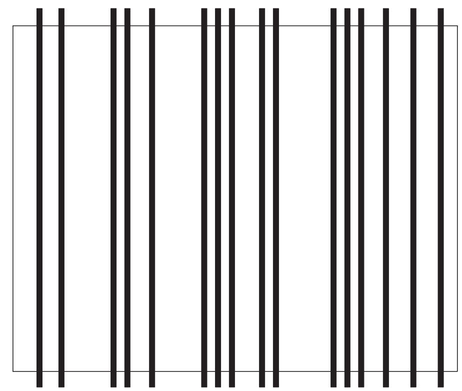
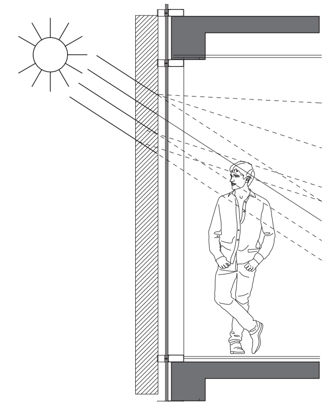


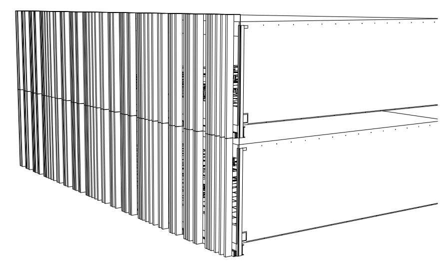


Elevation and Section

—7

Direct & Indirect

Open Offices



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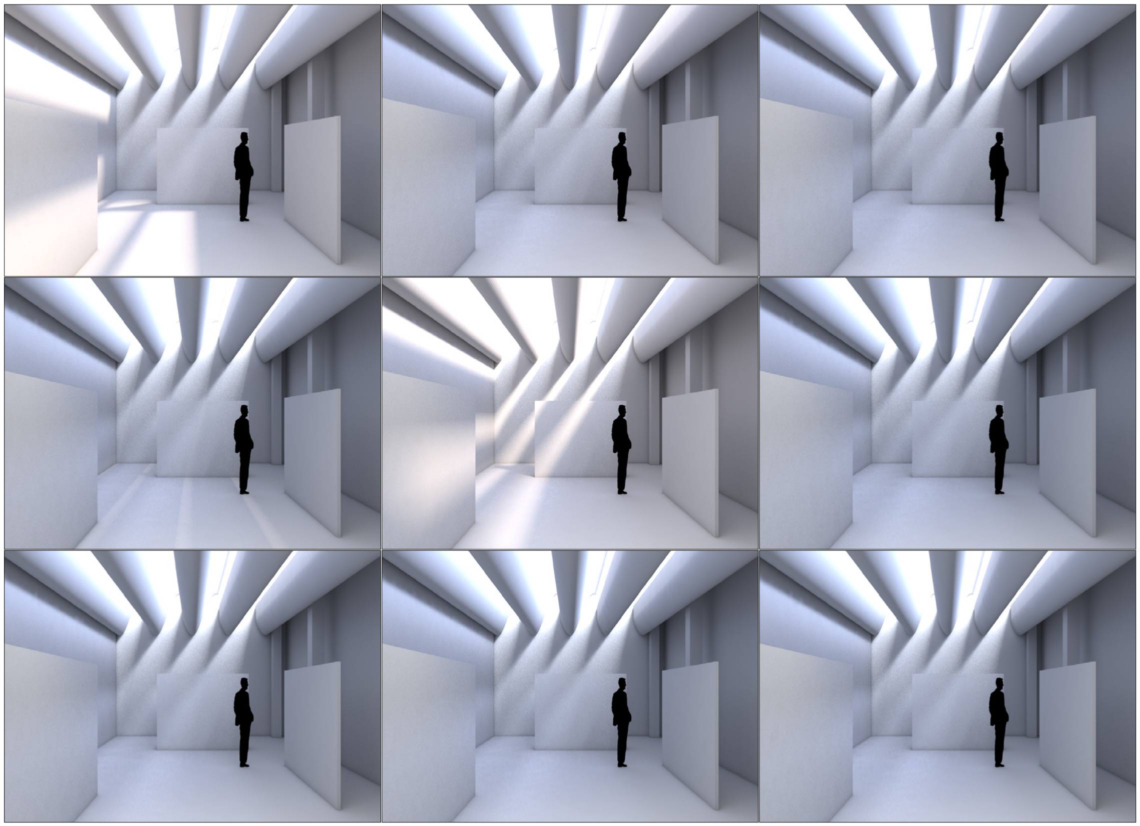

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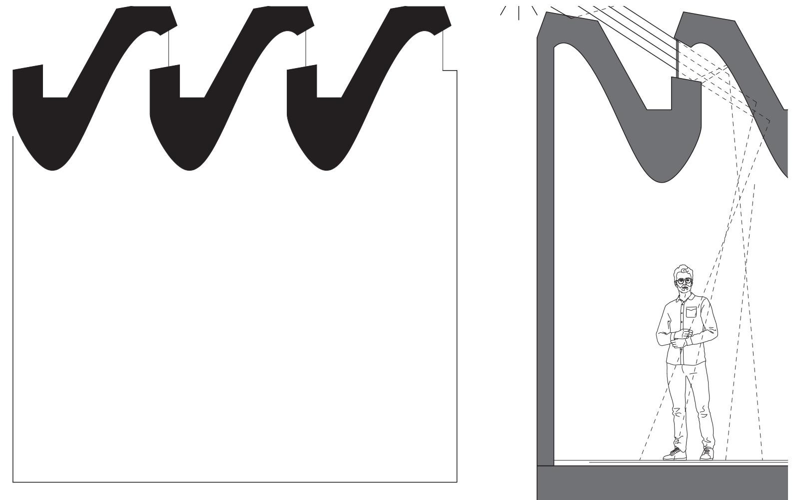
Building orientation: SW

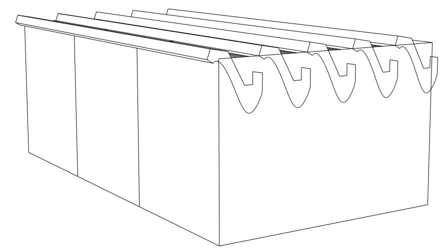


Elevation and Section

—8

Indirect

Gallery



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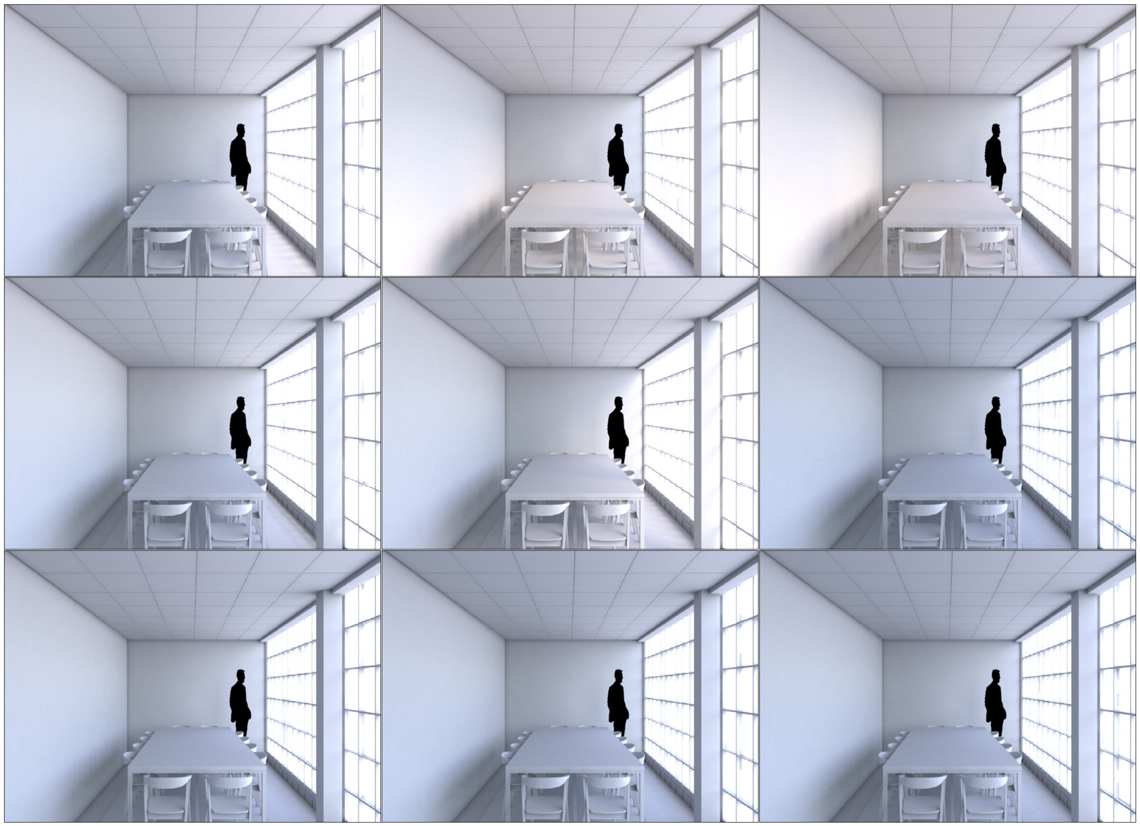

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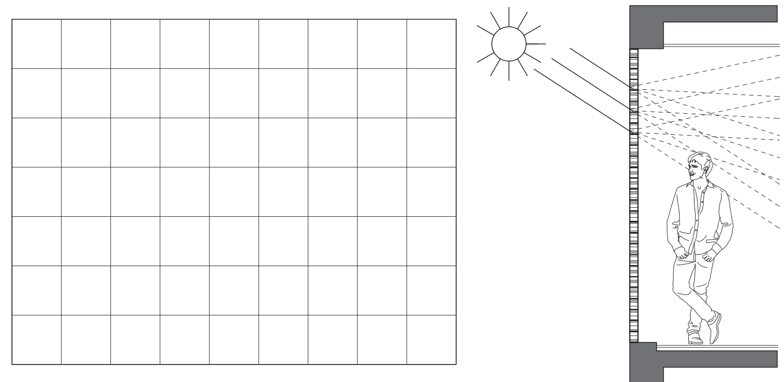
Building orientation: SW

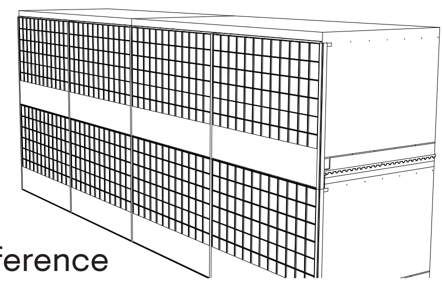


Elevation and Section

—9

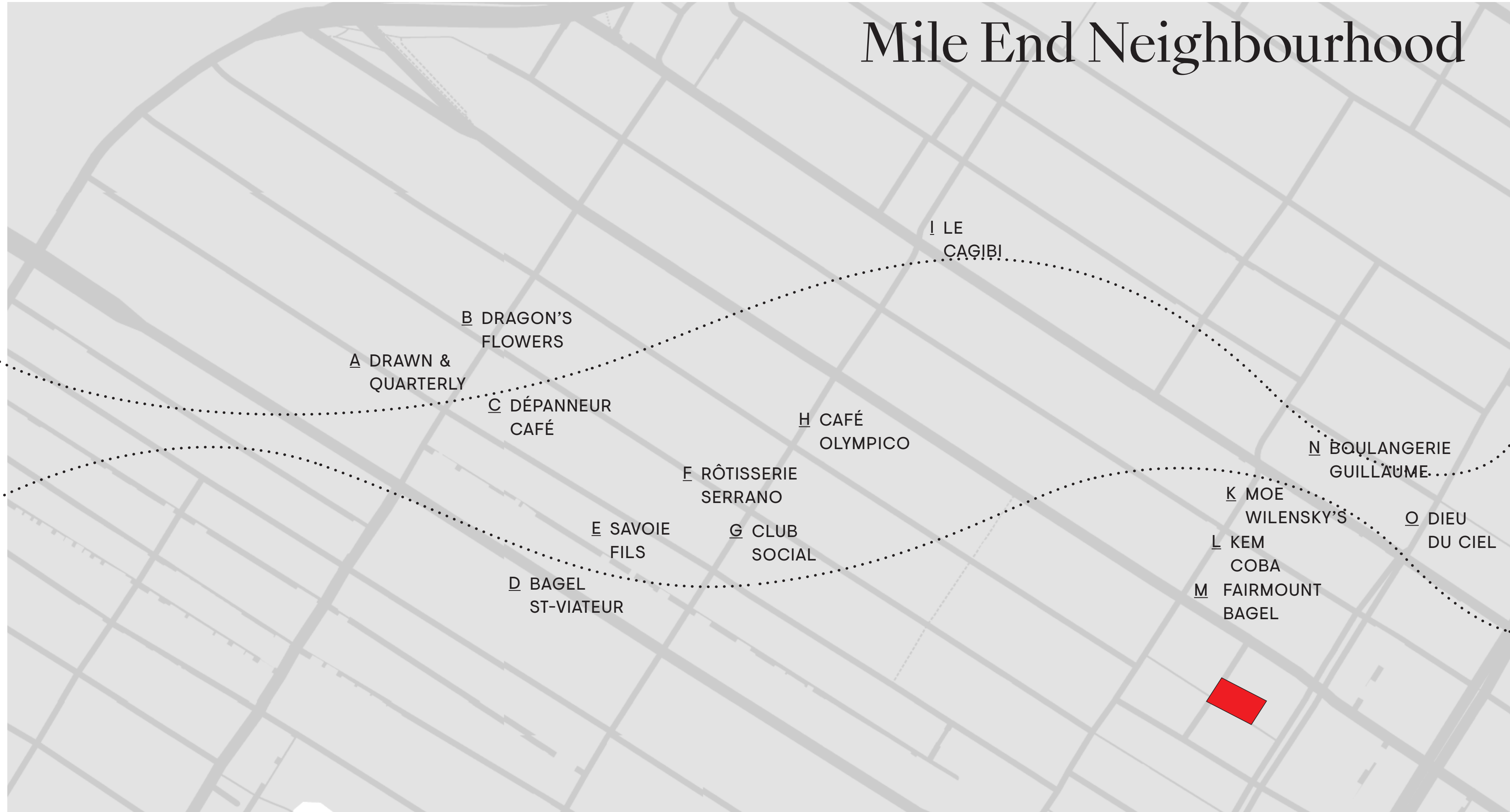
Indirect & Diffused

Closed Offices / Conference



05. Design Project

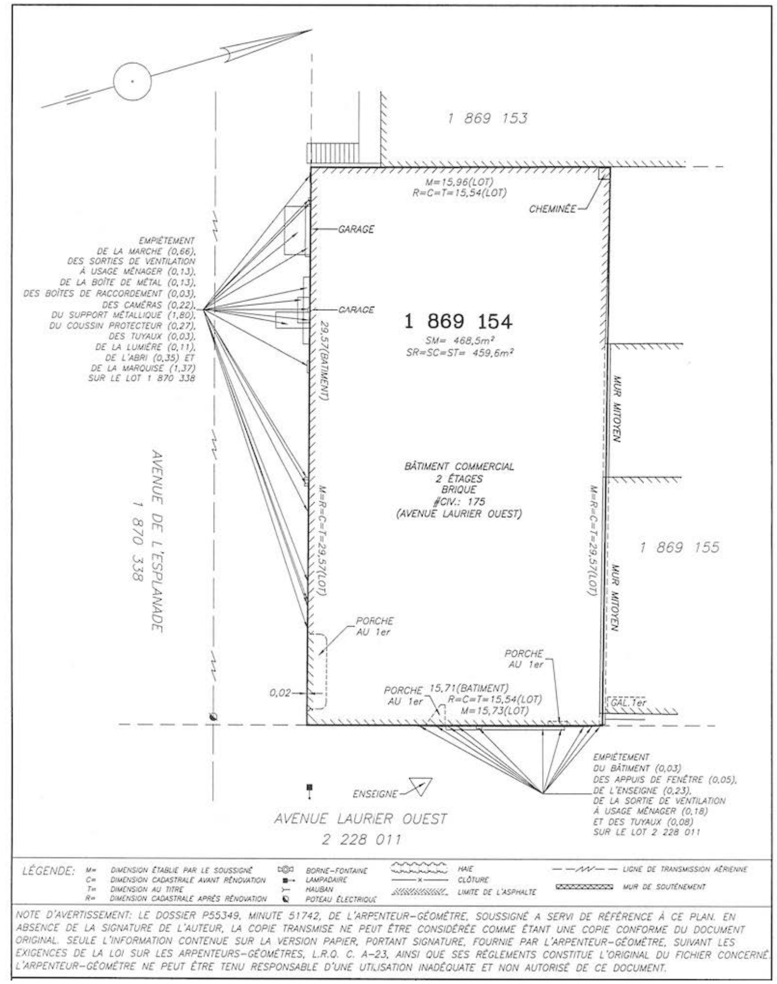
The topic of my thesis is the exploration of natural light within speculative buildings. I found that we tend to design buildings as glass boxes that offers little in terms of diverse illuminated environments. Therefore, I was interested in exploring the use of natural light within a building. My research explored 32 different facades that I then had surveyed by design professionals for the quality of light. My research has been narrowed down to nine lighting qualities that became the focus of my design project. These qualities range for direct and exaggerated to indirect and diffused. My design project attempts to demonstrate how these nine light qualities can be used within an urban mixed-use building.



Mile-End is a hip, laid-back neighbourhood with an artsy vibe, and multicultural roots. Indie shops selling records, books and vintage clothes are found throughout the area. Old-school bagel shops, and Italian cafés mix with media and gaming developers, bespoke fashion designers and creative design studios. Mile-End attracts professionals such a as app and website developers, designers, and advertisement agencies, making it a ideal location for a co-working space.

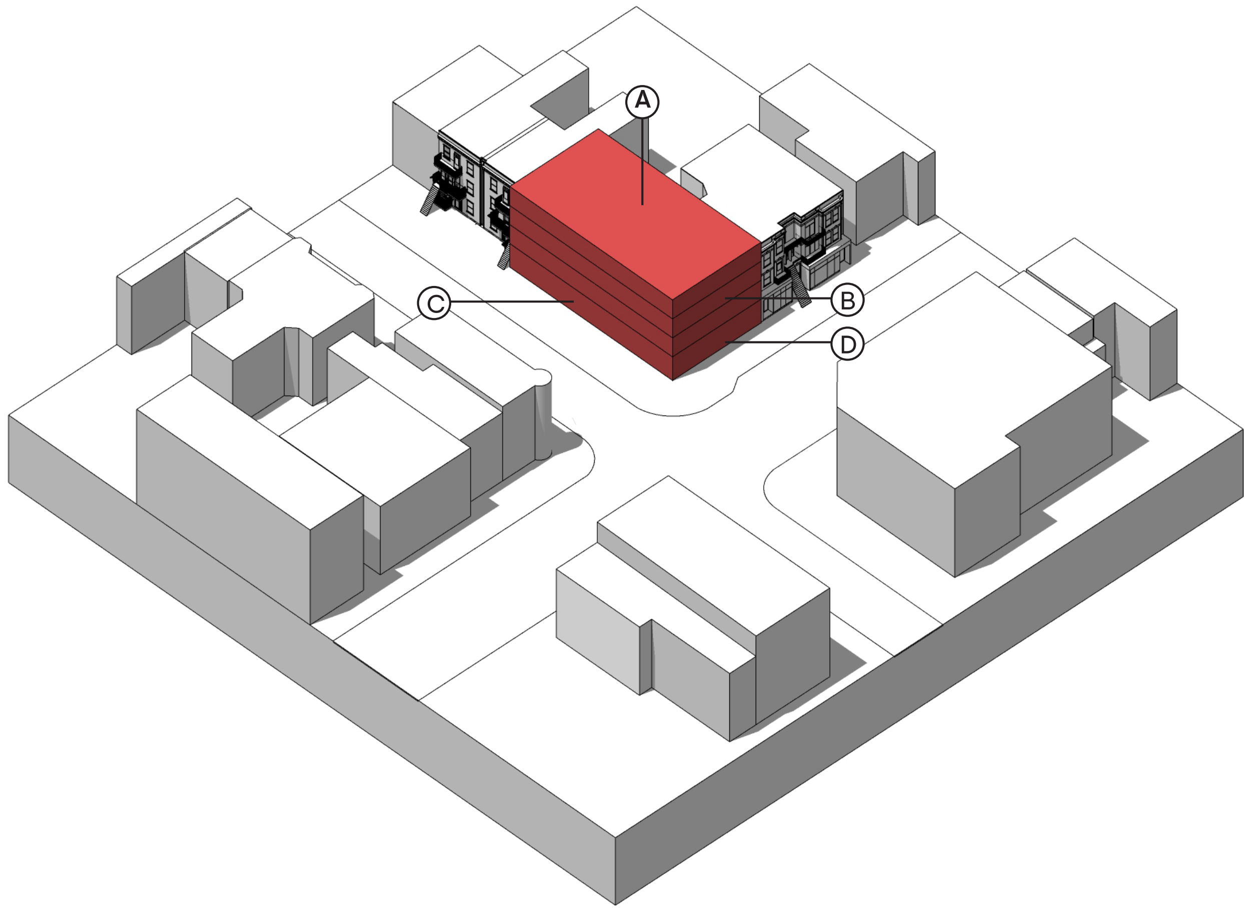
The proposed site is located at the heart of Mile-End, on the corner of Laurier and avenue de l'Esplanade. At the foot of Mount-Royal, the site offers views of the mountain and walking distance to the park. The urban area is conveniently within minutes of downtown, commuting by Uber, bicycle or public transit. With access to Laurier, the site promotes street front retail.

Site Plan



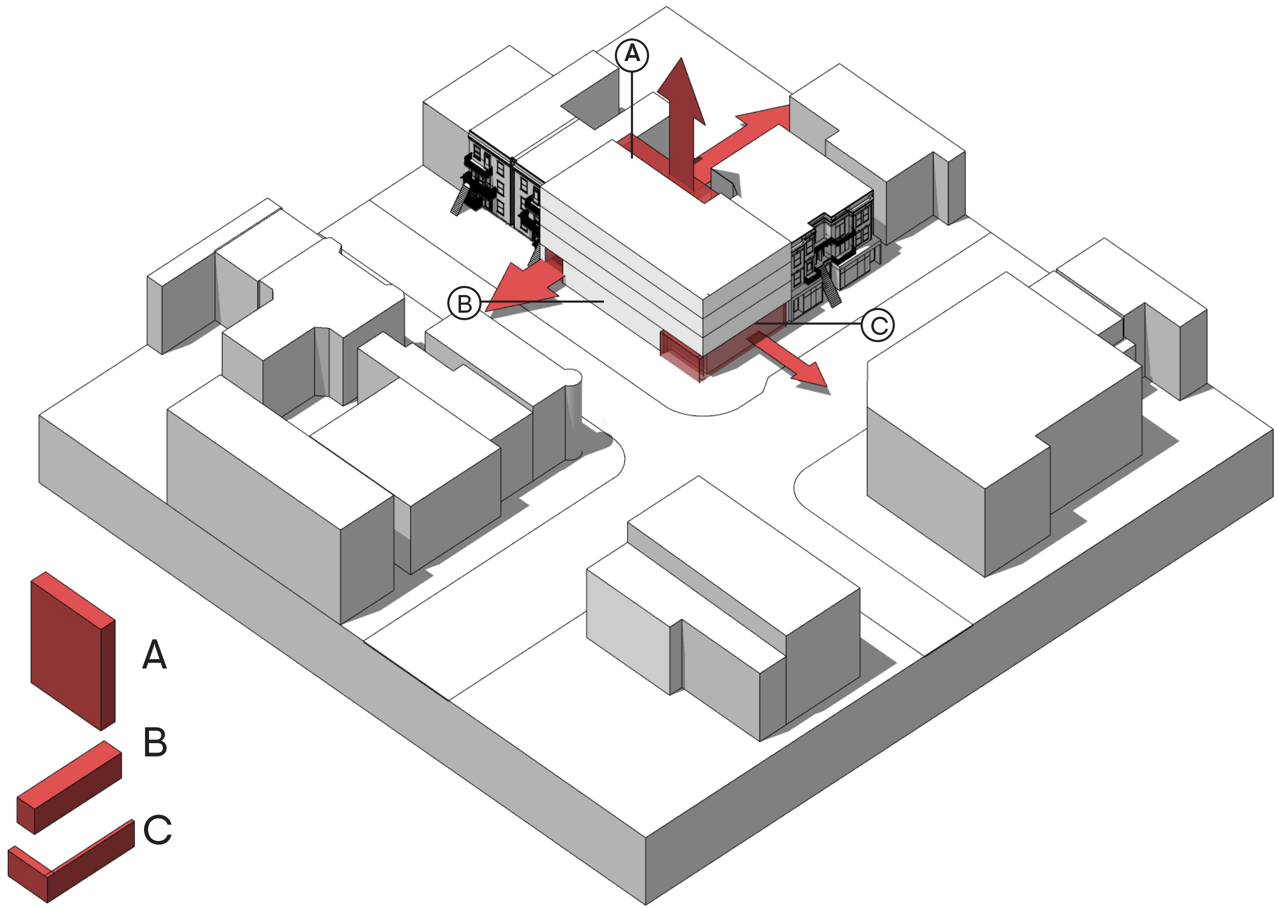
Certificate of Location
Address : 175 Laurier Ouest
Area of Lot: 500 square meters (approximation)
Authorized building height : 5 floors – 18 meters
Authorized land occupancy : 100%

Site Program Organization



A	Co-working office space
B	Apartments
C	Street level entrance, commerce - café, restaurant, and gallery.
D	Lower level communal space and services - pool, fitness, laundry, and storage.

Volumetric Study

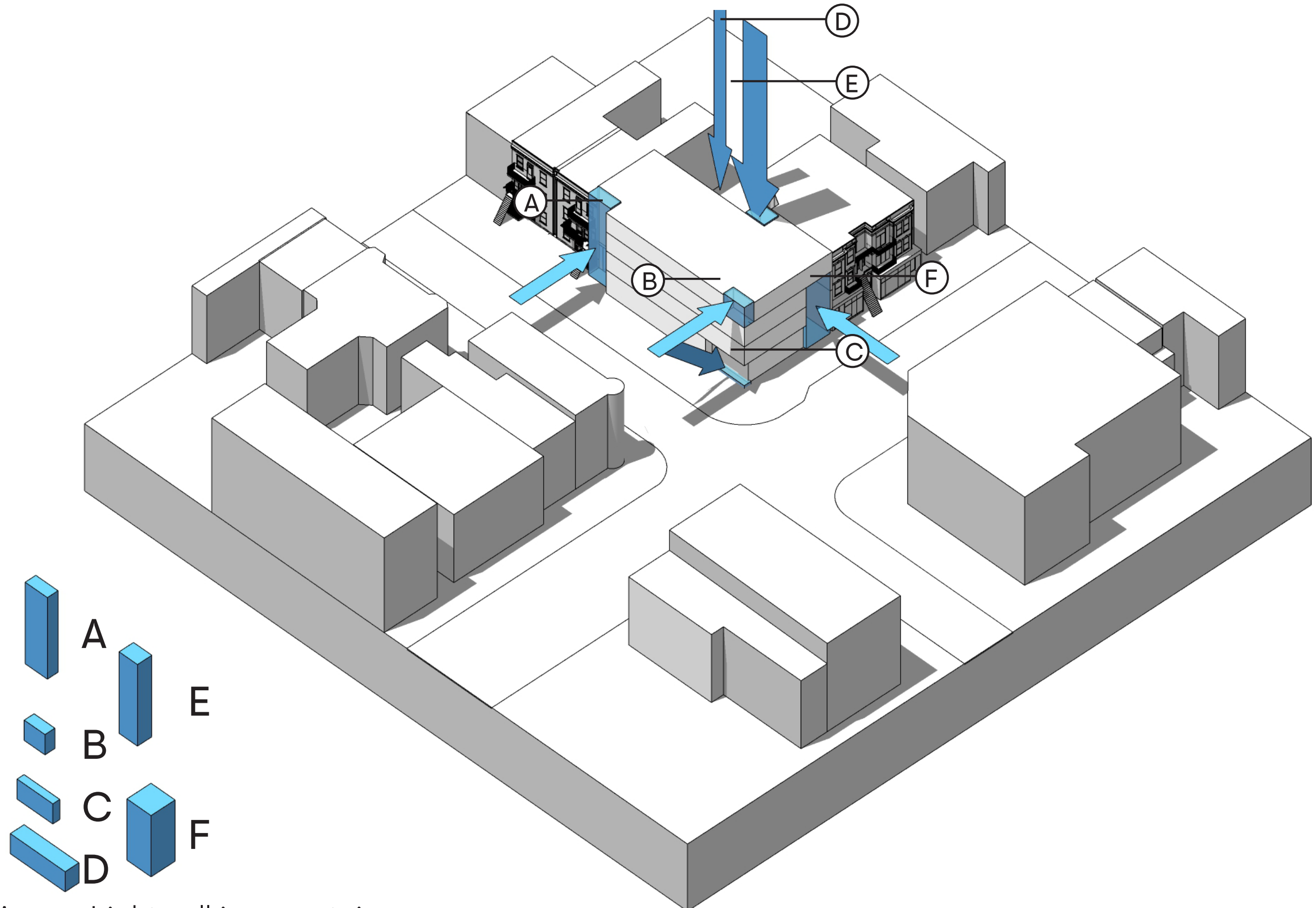


A Subtraction of the mass adjacent to neighbour creates a courtyard that permits light to enter closer to the center of the building. The “courtyard” provides an opportunity to bring light in from the top at the ground floor,

B Porte Cochere provides natural light into the connection from de l’esplanade and the rear alley.

C Recess at ground floor provides an opportunity to bring light into the lower level from the top.

Light Opportunities



A Lightwell in rear staircase
B Corner recess
C Lightwell to lower level pool
D Skylight to Gallery
E Lightwell in main staircase
F Open atrium to main entrance

Perspective Rendering

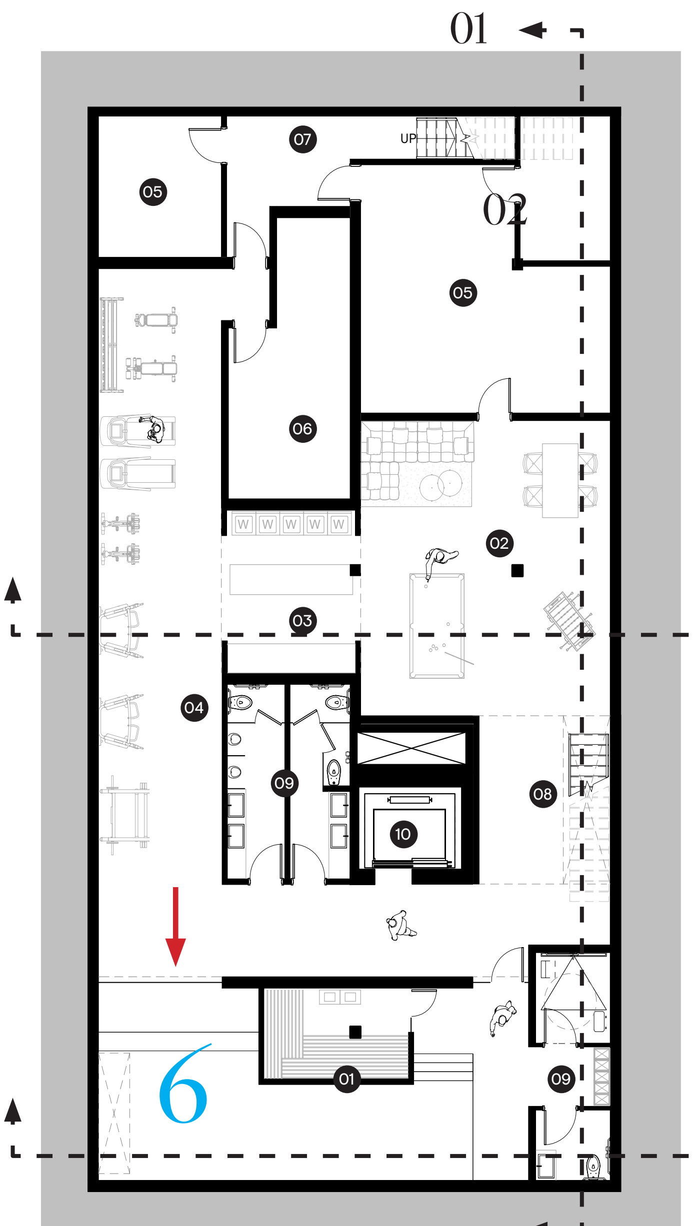
Corner Laurier and de l'Esplanade

Legend:

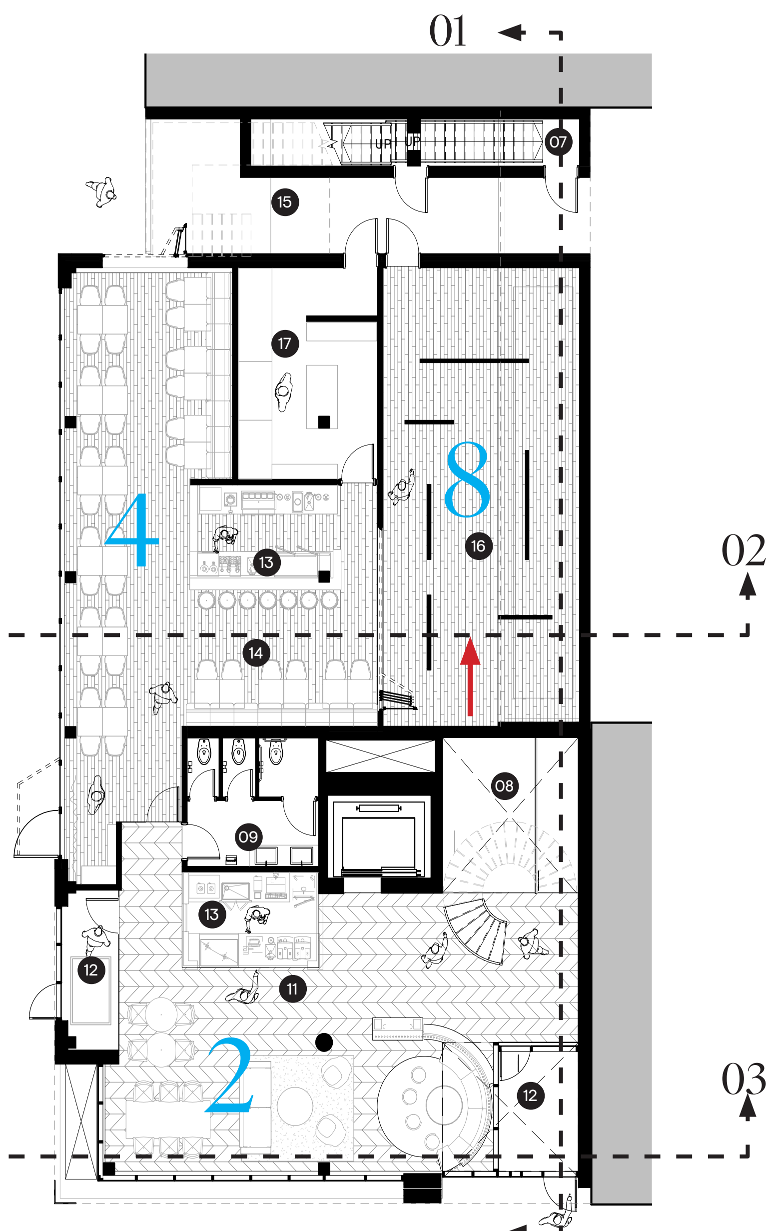
- 01 Pool
- 02 Communal Area
- 03 Laundry
- 04 Fitness
- 05 Storage
- 06 Mechanical Room
- 07 Egress Stair
- 08 Staircase
- 09 Washrooms
- 10 Elevator
- 11 Cafe
- 12 Entrance
- 13 Bar
- 14 Restaurant
- 15 Alley
- 16 Gallery
- 17 Kitchen
- 18 Suite
- 19 Atrium - Open to Below
- 20 Co-working Lounge
- 21 Co-working shared desks
- 22 Co-working dedicated desks
- 23 Meeting room
- 24 Conference room

North

Scale 1:200



Lower Level Plan



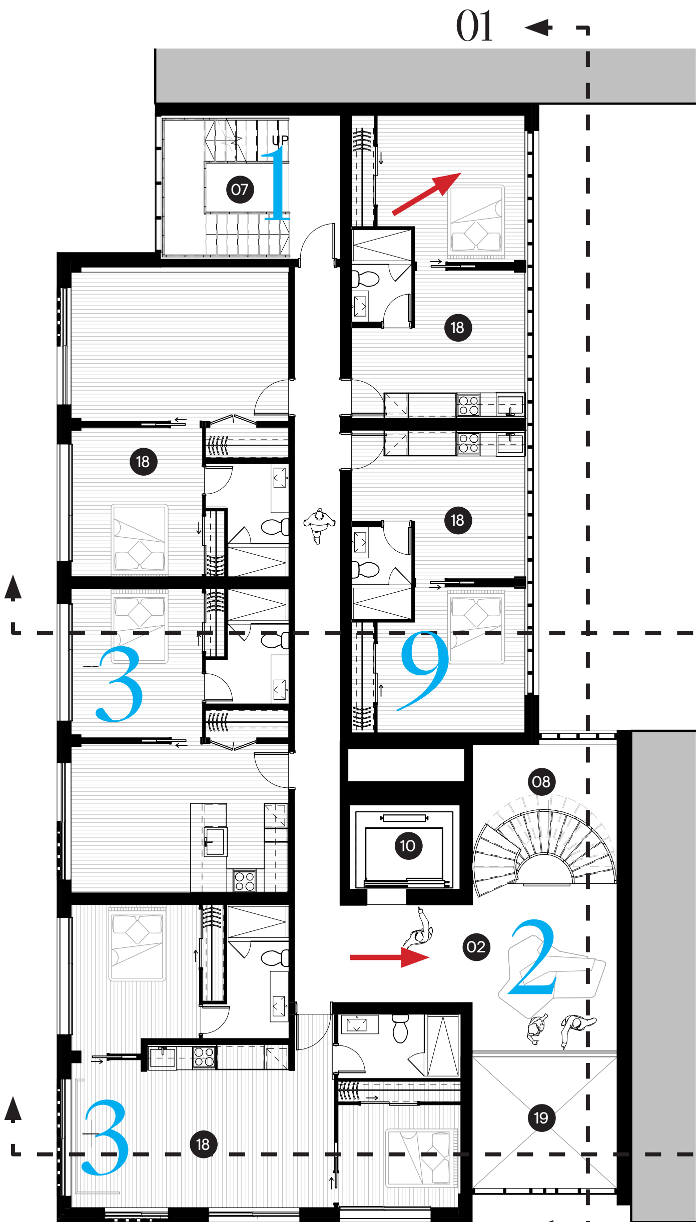
Ground Floor Plan

Legend:

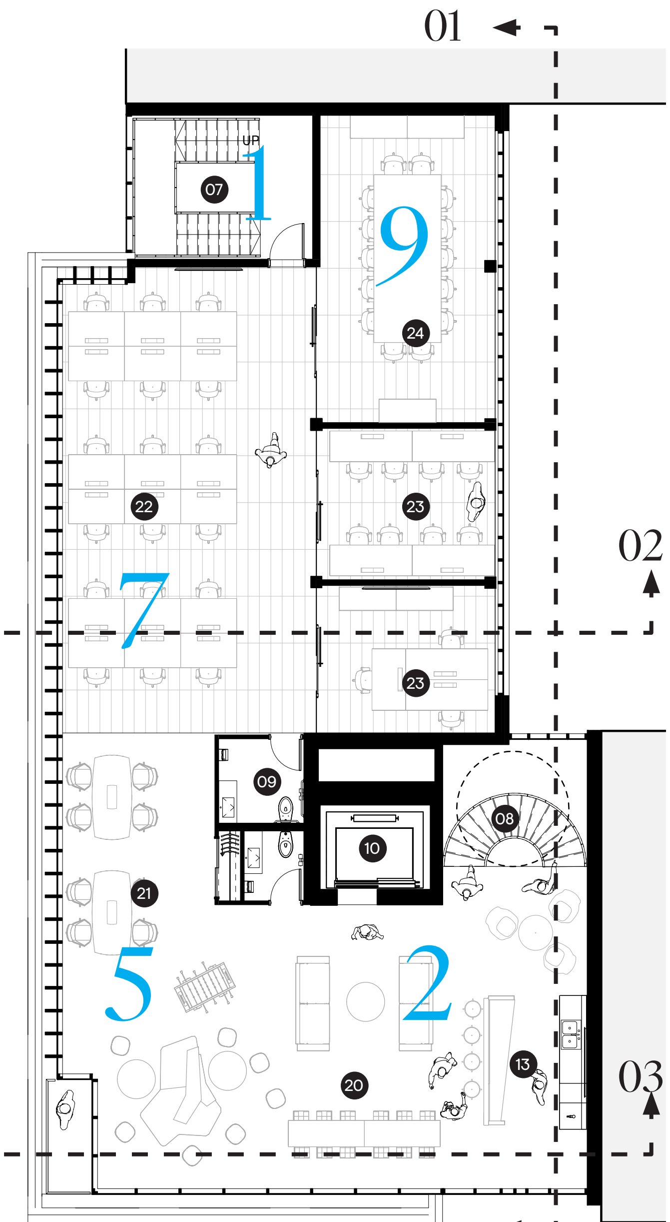
01	Pool
02	Communal Area
03	Laundry
04	Fitness
05	Storage
06	Mechanical Room
07	Egress Stair
08	Staircase
09	Washrooms
10	Elevator
11	Cafe
12	Entrance
13	Bar
14	Restaurant
15	Alley
16	Gallery
17	Kitchen
18	Suite
19	Atrium - Open to Below
20	Co-working Lounge
21	Co-working shared desks
22	Co-working dedicated desks
23	Meeting room
24	Conference room

North

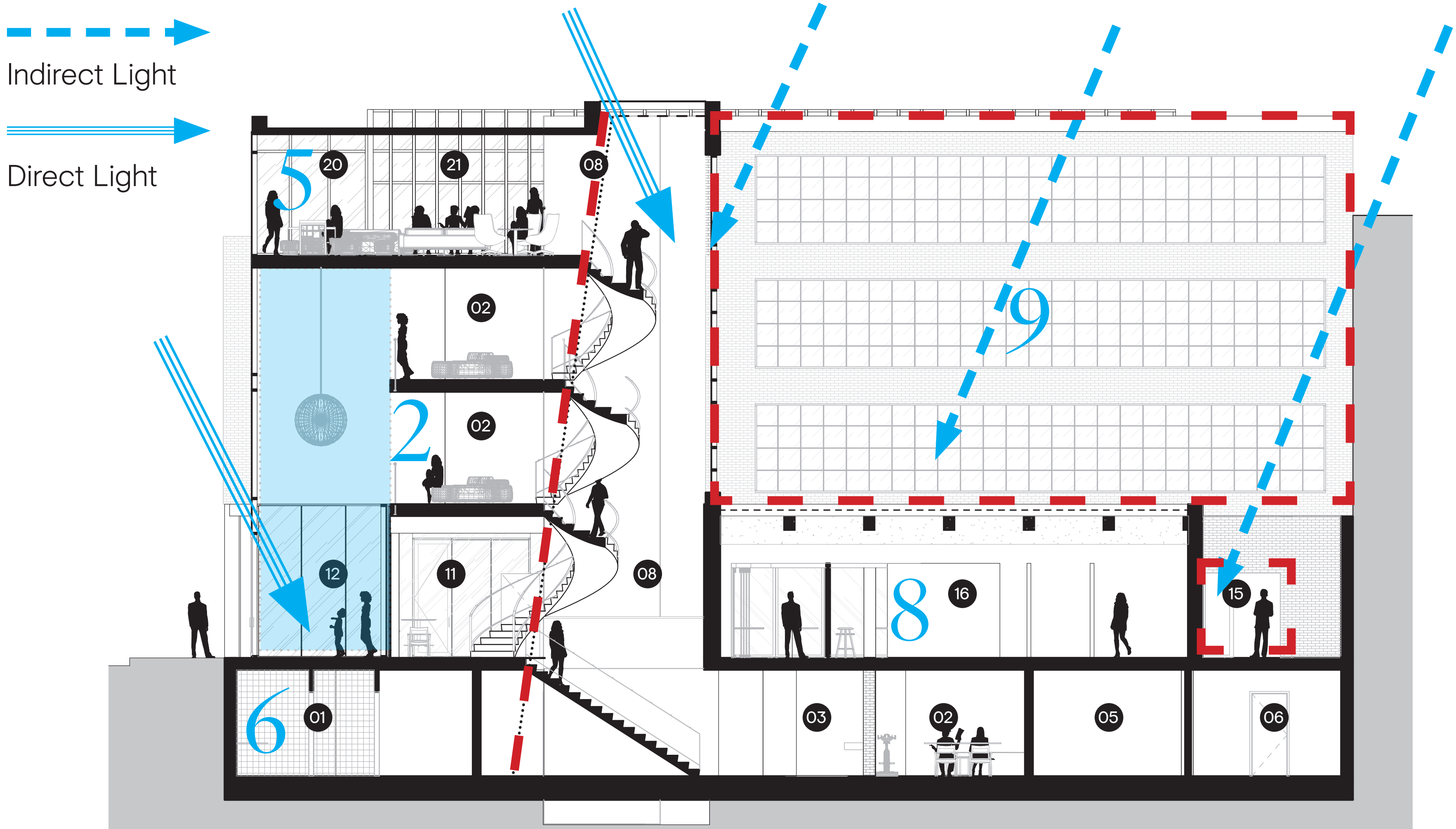
Scale 1:200



Level 2 & 3 - Suites

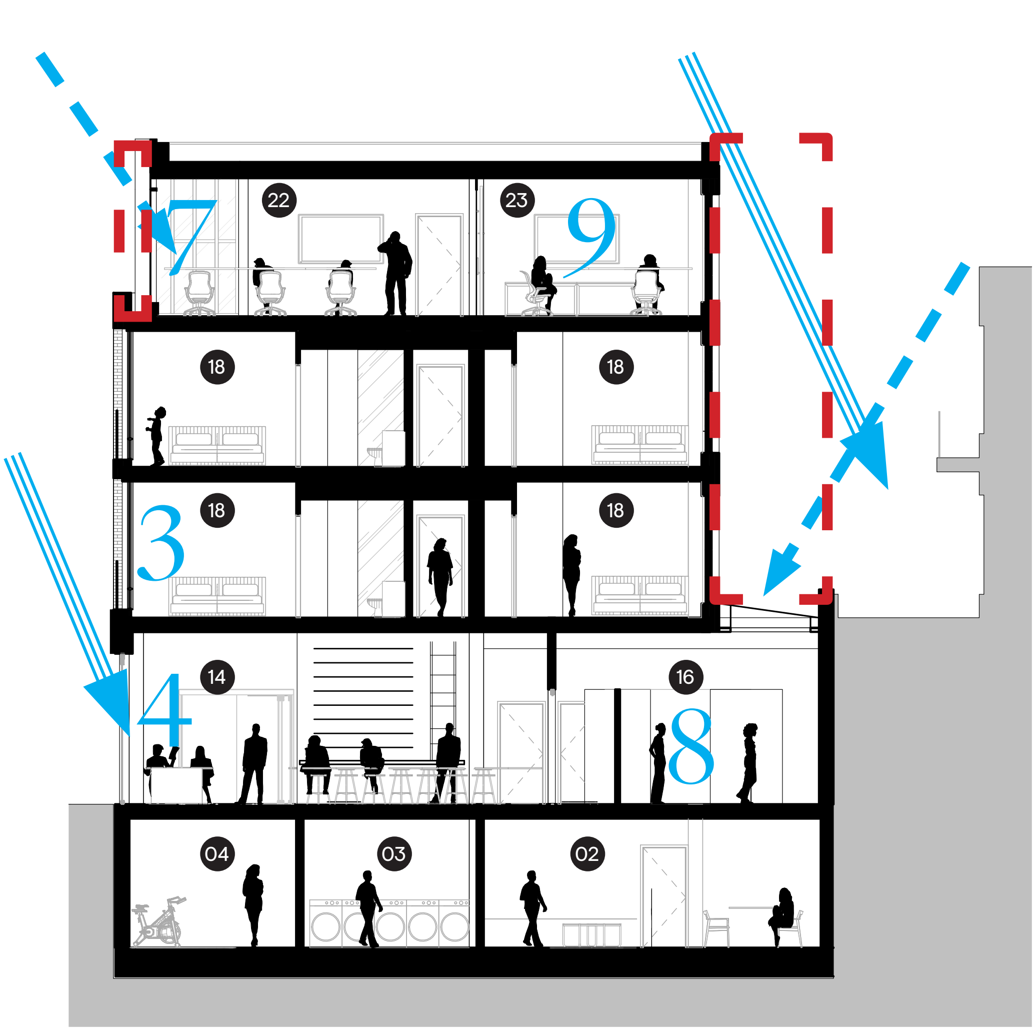


Level 4 - Co-working



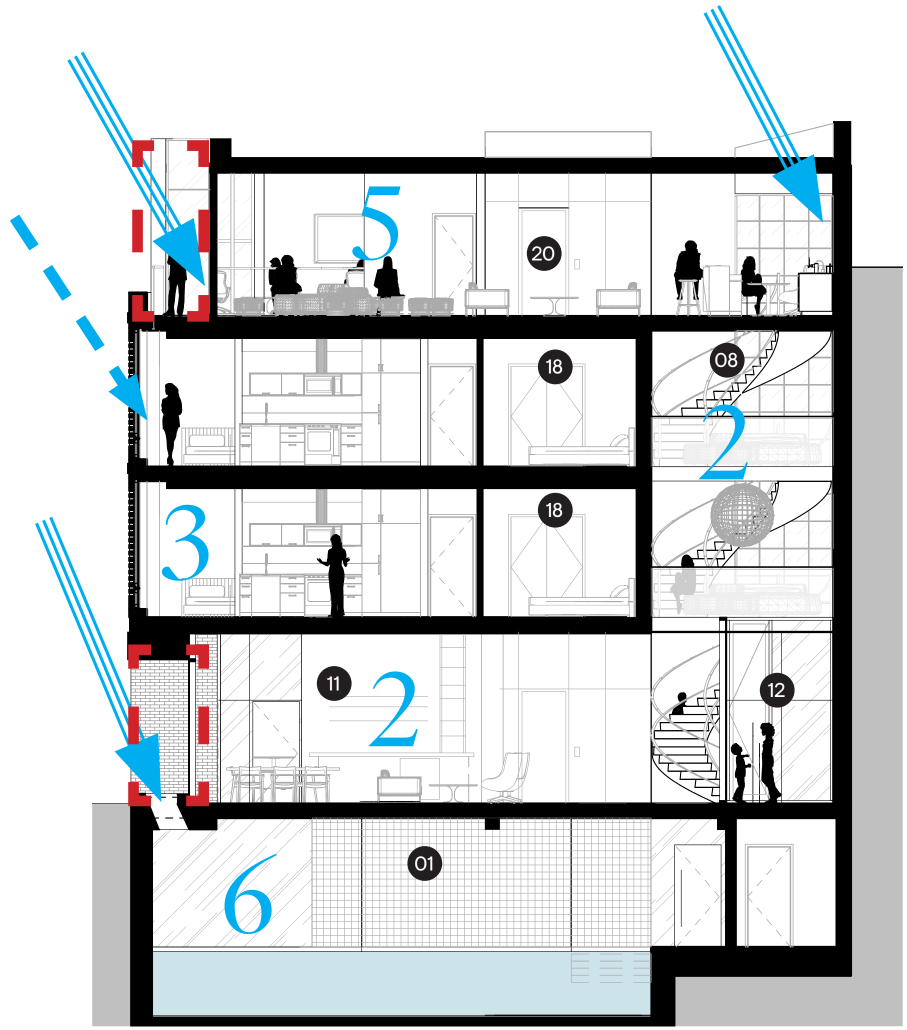
Scale 1:200

Section 01 - Gallery and Stairwell



Scale 1:200

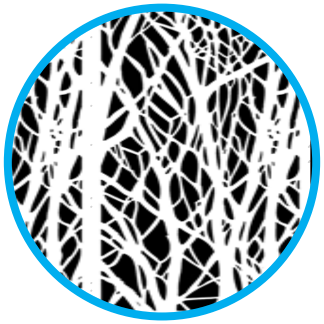
Section 02 - Apartments



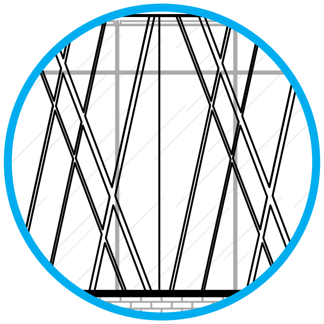
Section 03 - Pool & Office Lounge

Elevation - Laurier

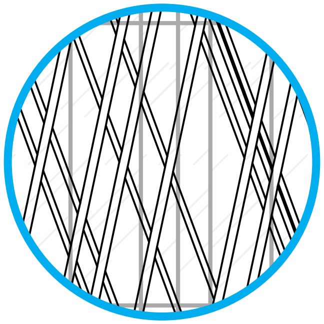
Scale 1:200



-2 Light quality selected for a stimulating environment at the ground floor cafe.

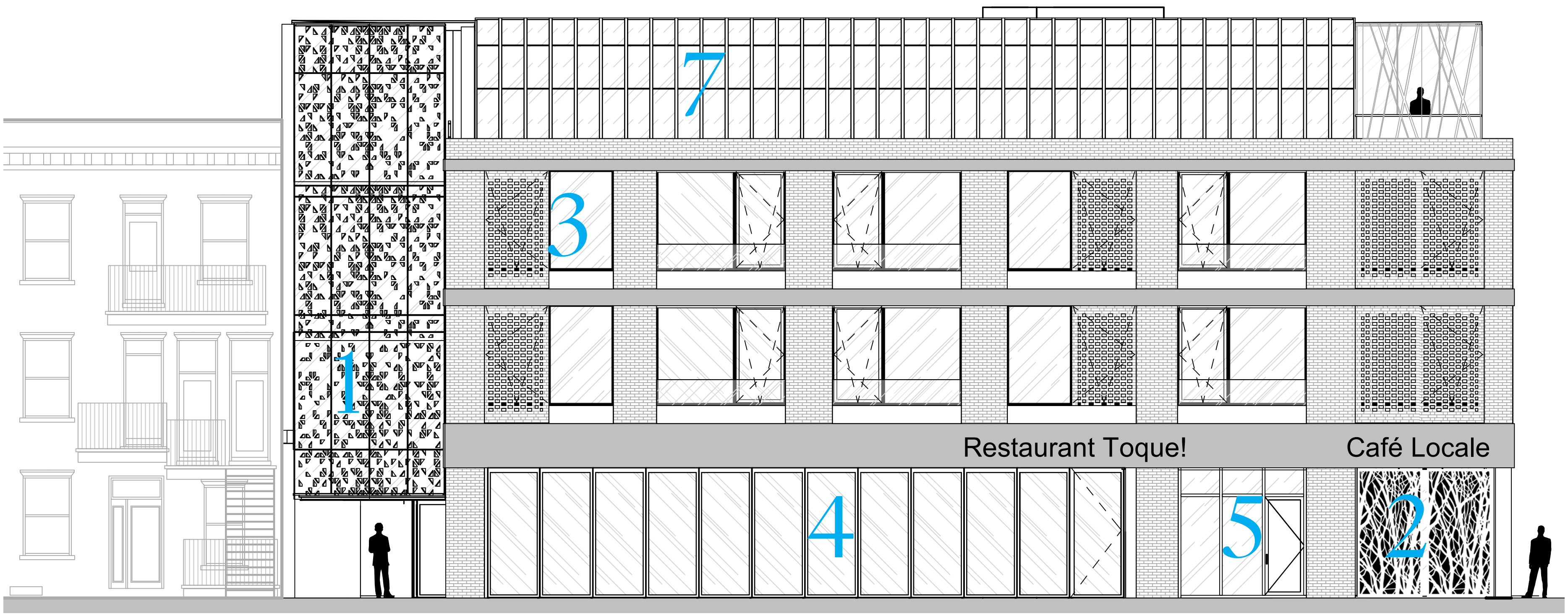


-5 Light quality selected for the office lounge, temporary work areas does not require specify light treatment.

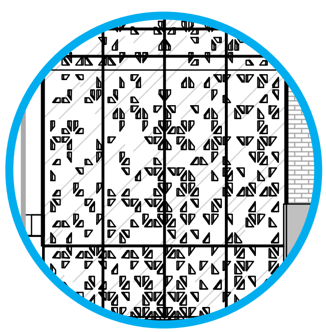


-2 Light quality selected for the reception and entrance staircase. Dramatic qualities are stimulating and vibrant.

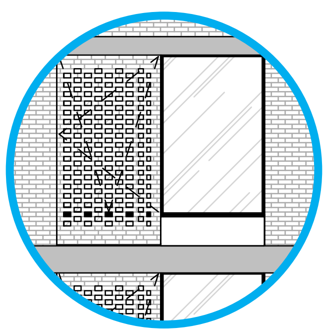
Elevation - de l'Esplanade



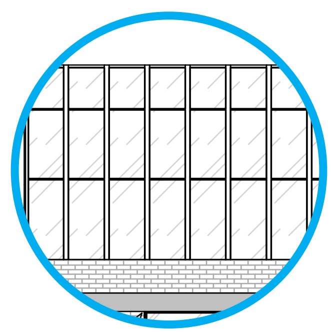
Scale 1:200



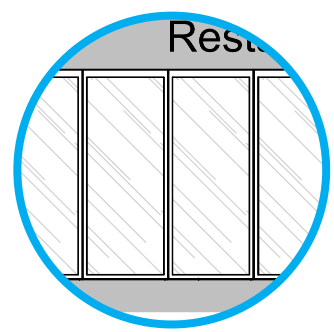
-1 Light quality selected for the stairwell becomes a transitional space for both movement and visual interest.



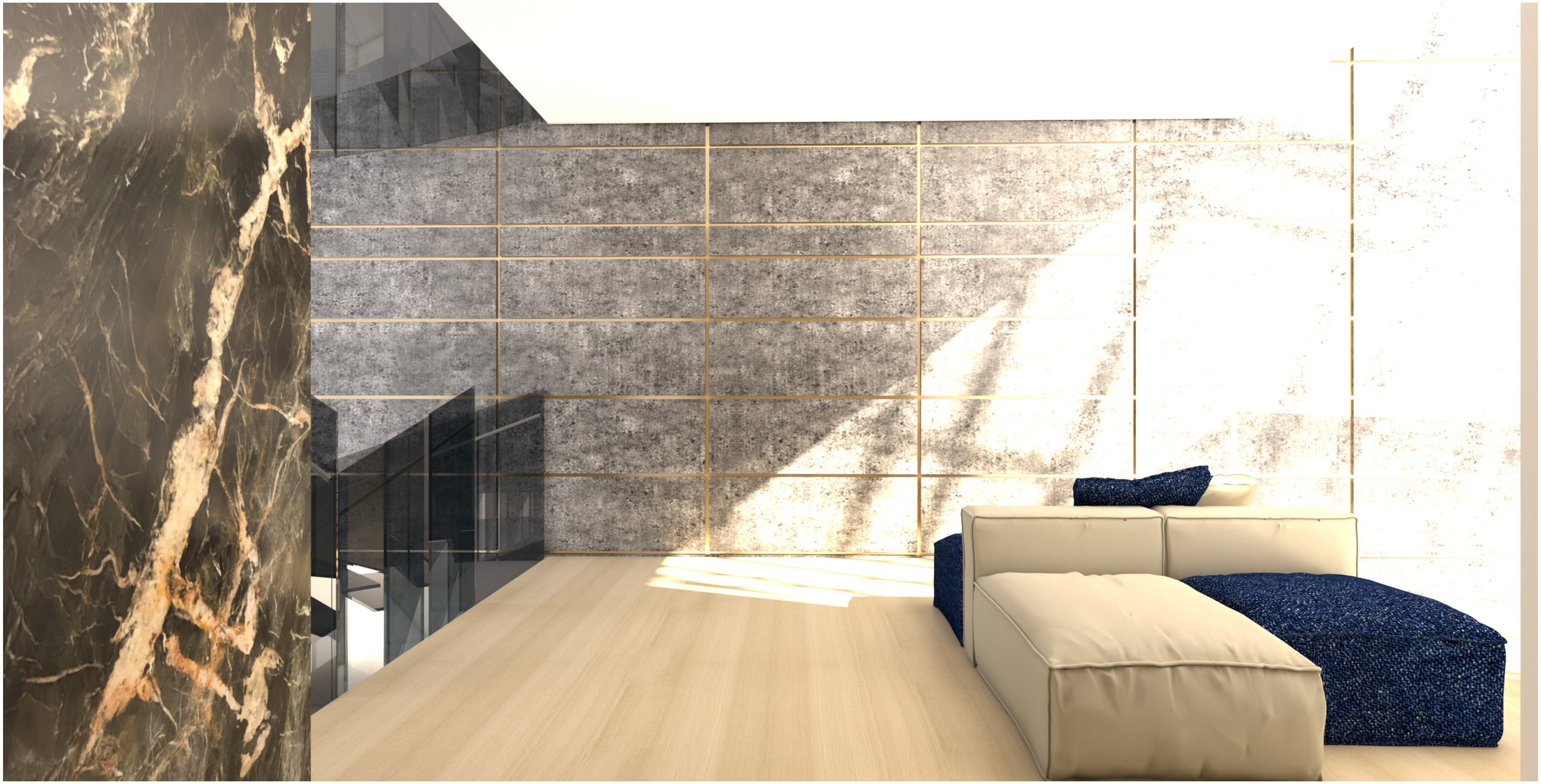
-3 Light quality both direct and screened provides dynamic shadows and privacy, while contrasted with driect light.



-7 Light quality is primarily indirect by diflecting west oriented direct light off deep fins, resulting in a even and diffused light.



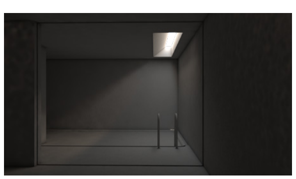
-4 Light quality partially direct allows both views in and out of the restaurant space. The movable wall opens to the street.

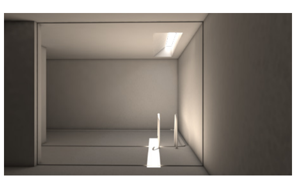


—2 Direct & Dramatic

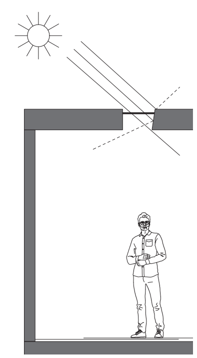
The staircase that connects each level is illuminated by two sources of light. On the right light penetrates the dramatic curtain wall that cast shadows on the concrete wall. The light travels across the space reaching and reflecting off the elevator stone wall. Momentarily light enters from the skylight inverting the perceptual experience.

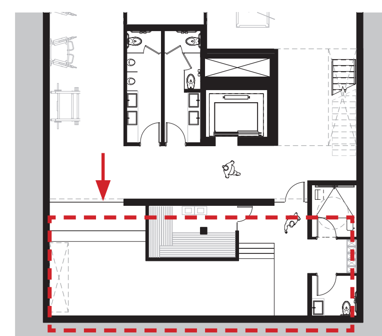
—6 Selectively Direct



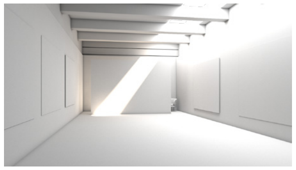


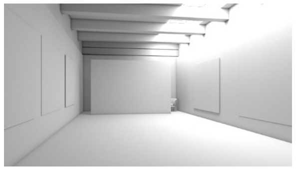
Unexpectdly light enters through a linear slot at the street level to the pool level below grade. The setback allows natural light to transcend into the volume and cast a direct beam that moves across the wall and water daily. The light further reflects off the ceramic and water creating caustis and other reflections, animating the underground space.



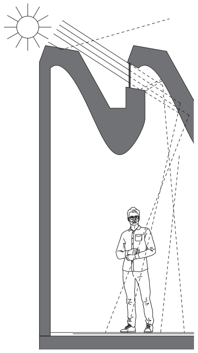


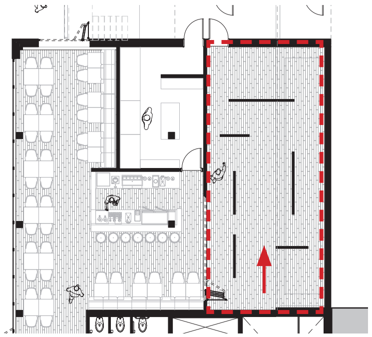
—8 Indirect



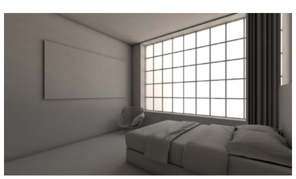


Natural light is used to showcase the artwork, but attention to harsh direct light and glare is important. By diffusing the light, the gallery is illuminated by natural light reflected through a skylight. During summer mornings natural light is permitted to enter directly and cast a beam of light on the back wall. The gallery can be curated to feature this effect.

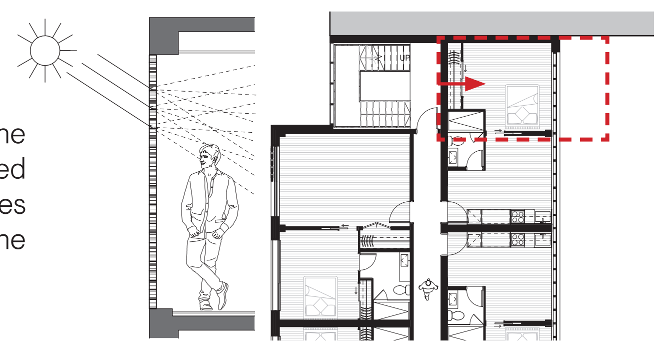




— 9 Indirect & Diffused



The light quality effects the sense of spaciousness. For the small apartments on the back facade, a wall of diffused light enlarges the space, while the screened glass provides privacy. Views out into the alley were not conserved. The colour of light casts a hue over the course of a day.



Perspective Rendering - Entrance

Closing Remarks

My research and design project were an exploration of natural light. The exploration has led me to a palette of nine light qualities. The palette became a tool used to demonstrate the luminous effects and spatial qualities. The final project demonstrates the appeal of diversity of light through multiple illuminated environments within an urban mix-use building.

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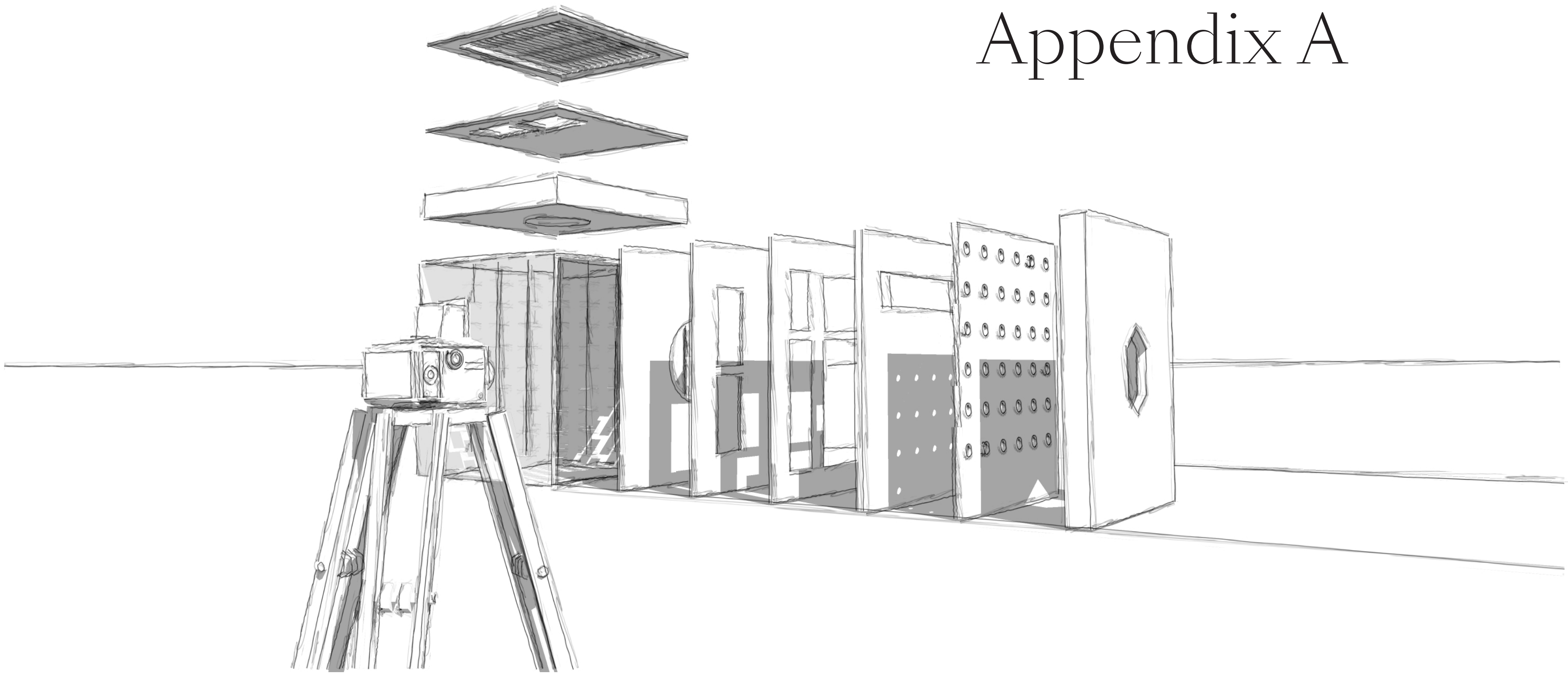
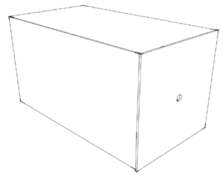
06. Experiment Results

Appendix A



*All light measurements for the following experiments are in lux (lx). A lux is the SI unit of measurement for illuminance, measuring luminous flux per area. A lux is equal to one lumen per square meter (1 lx = 1 lm/m²). In photometry, this is a measurement of the intensity as perceived by the human eye. A lux is analogous to the radiometric unit watts per square meter, but with power at each wavelength weighted according to the luminosity function. Conversion between the two units is possible, but power is dependent on the light source. For example, the sun requires multiplication factor of 4.02 to convert lux to power (Lux to W/m²).

Aperture 01 – Pin-hole



Isometric

Results

Light Meter Readings in Lux:

1 2 5 7 6 9

Average Illuminations (lx): 5lx

Oblique View

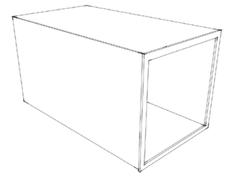
Semantic Scale Rating

Low Contrast	● ○ ○ ○ ○	High Contrast
Uniform	● ○ ○ ○ ○	Focused
Subtle	● ○ ○ ○ ○	Vibrant
Simple	● ○ ○ ○ ○	Complex
Calming	● ◐ ○ ○ ○	Stimulating
Enlarging	○ ○ ○ ○ ●	Confining

Discussion

The pinhole aperture examines the effects of a single small opening. The results is a single concentrated point of light that is lost within the space. The aperture creates an interest when the unique point of light moves along each surfaces along with the procession of the sun. The natural connection is strong between the dim space and the yearning for natural light through the small void.

Aperture 02 –Floor to Ceiling



Isometric

Results

Light Meter Readings in Lux:

1236 1680 2575 1481 3292 3993

Average Illuminations (lx): 2376lx

Oblique View

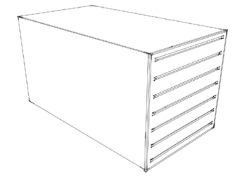
Semantic Scale Rating

Low Contrast	● ○ ○ ○ ○	High Contrast
Uniform	● ○ ○ ○ ○	Focused
Subtle	○ ○ ◐ ● ○	Vibrant
Simple	◐ ● ○ ○ ○	Complex
Calming	○ ○ ○ ◐ ●	Stimulating
Enlarging	● ○ ○ ○ ○	Confining

Discussion

The floor to ceiling opening examines the effects of an "apertureless" design. The result is an abundance of uncontrolled natural light. One can argue that there is a connection between the natural environment and architecture through the large aperture, but the large aperture has turned into a mere absence of the wall. The illumination readings are extremely and uniform and excessively high.

Aperture 03 - Horizontal Sidelight



Isometric

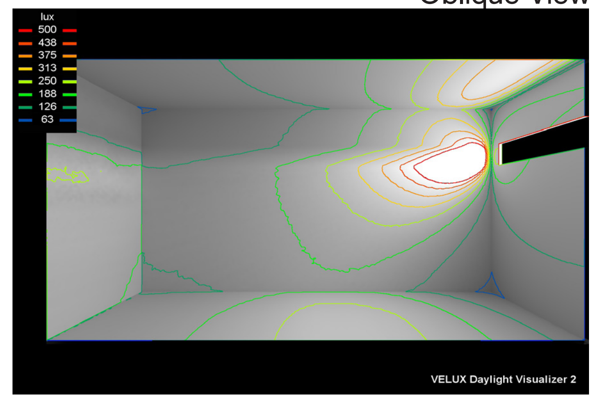
Results

Light Meter Readings in Lux:

201 145 216 226 192 140

Average Illuminations (lx): 187lx

Oblique View



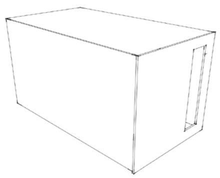
Semantic Scale Rating

Low Contrast	○ ○ ◐ ● ○	High Contrast
Uniform	○ ○ ○ ● ◐	Focused
Subtle	○ ◐ ● ◐ ○	Vibrant
Simple	○ ○ ◐ ● ◐	Complex
Calming	○ ○ ○ ● ○	Stimulating
Enlarging	○ ○ ◐ ● ○	Confining

Discussion

The horizontal aperture examines the effects of a horizontal band opening above sill height. The results is a bleed of light on the adjacent wall and hot-spot on the immediate ceiling. The light penetrates deep and disperses evenly along the floor. There is subtle contrast within the space. The illumination reading are relatively close and uniform.

Aperture 04 - Vertical Sidelight



Isometric

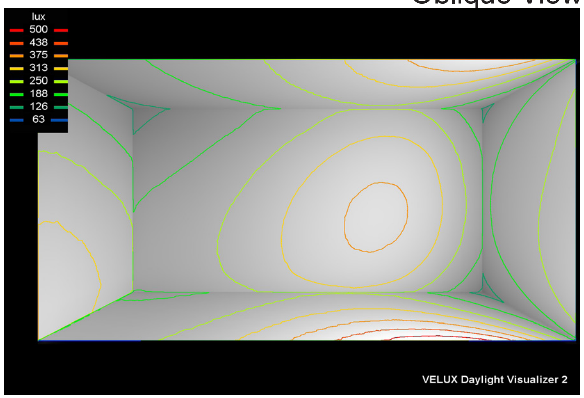
Results

Light Meter Readings in Lux:

203 250 236 765 265 321

Average Illuminations (lx): 350lx

Oblique View



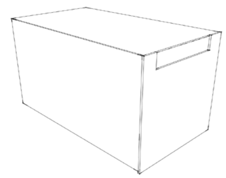
Semantic Scale Rating

Low Contrast	◎	●	◎	○	○	High Contrast
Uniform	○	●	○	○	○	Focused
Subtle	◎	●	○	○	○	Vibrant
Simple	○	●	○	○	○	Complex
Calming	◎	●	○	○	○	Stimulating
Enlarging	○	●	◎	○	○	Confining

Discussion

The vertical aperture examines the effects of a vertical sidelight opening from floor to ceiling. The result is a stripe of light along the floor. The light is immediately diffused at the floor and gradually decreases further into the space. The band of light creates drastic contrast and interest. The illumination reading are relatively close and uniform apart from the direct daylight.

Aperture 05 - Upper Sidelight



Isometric

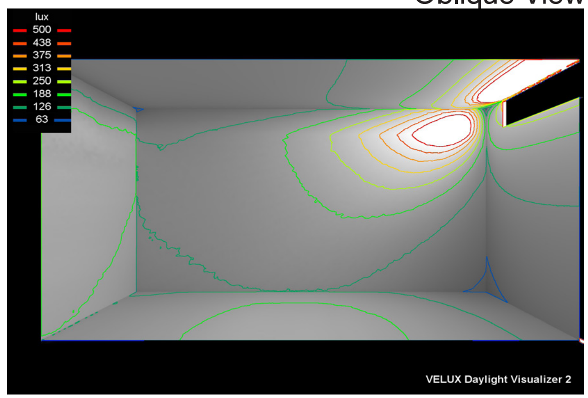
Results

Light Meter Readings in Lux:

200 154 170 118 143 129

Average Illuminations (lx): 413lx

Oblique View



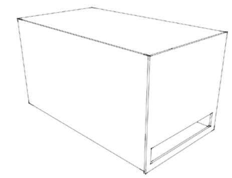
Semantic Scale Rating

Low Contrast	○	○	○	●	◎	High Contrast
Uniform	○	○	○	◎	●	Focused
Subtle	○	○	◎	●	◎	Vibrant
Simple	○	●	◎	◎	○	Complex
Calming	○	◎	○	●	○	Stimulating
Enlarging	○	○	○	●	◎	Confining

Discussion

The upper aperture examines the effects of a horizontal band opening at ceiling height. The results is a bleed of light on the adjacent wall and hot-spot on the immediate ceiling. The light penetrates deep and disperses evenly along the floor. There is subtle contrast within the space. The illumination reading are relatively close and uniform.

Aperture 06 - Base Sidelight



Isometric

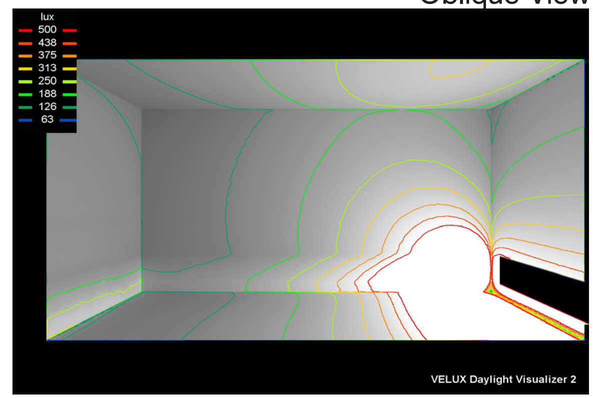
Results

Light Meter Readings in Lux:

147 126 115 101 280 1710

Average Illuminations (lx): 413lx

Oblique View



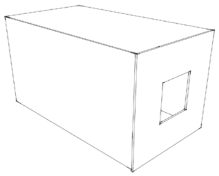
Semantic Scale Rating

Low Contrast	○	○	○	●	◎	High Contrast
Uniform	○	○	○	◎	●	Focused
Subtle	○	○	◎	●	◎	Vibrant
Simple	○	●	◎	◎	○	Complex
Calming	○	◎	○	●	○	Stimulating
Enlarging	○	○	○	●	◎	Confining

Discussion

The base aperture examines the effects of a sidelight positioned along the floor of the space. The result is a stripe of light along the floor that reflects into the space. The light is immediately diffused at the floor and gradually decreases further into the space band of light and inverted direction of light creates a surreal environment. The illumination reading are highly diverse.

Aperture 07 - Square Sidelight



Isometric

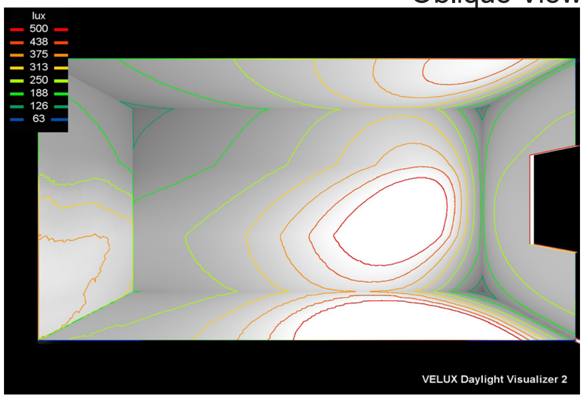
Results

Light Meter Readings in Lux:

418 408 760 500 257 485

Average Illuminations (lx): 471lx

Oblique View



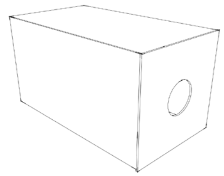
Semantic Scale Rating

Low Contrast	○	◐	●	◐	○	High Contrast
Uniform	○	○	○	●	○	Focused
Subtle	○	○	○	◐	●	Vibrant
Simple	○	○	◐	◐	◐	Complex
Calming	○	○	◐	●	◐	Stimulating
Enlarging	○	●	◐	○	○	Confining

Discussion

The square sidelight aperture examines the effects of a square opening in the center of the wall. The results is a projection of light in the shape of the opening. This heightens the awareness of the aperture. The light reflects throughout the space, but a focus is formed by the light in the center of the space. There is subtle contrast within the space and a significant variation in the light meter readings.

Aperture 08 - Circular Sidelight



Isometric

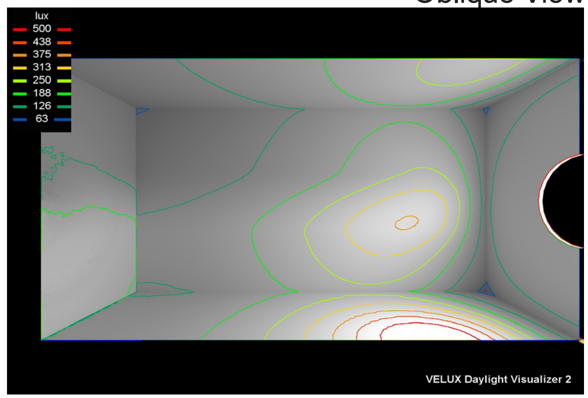
Results

Light Meter Readings in Lux:

367 272 593 204 131 480

Average Illuminations (lx): 341lx

Oblique View



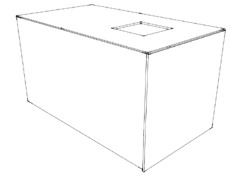
Semantic Scale Rating

Low Contrast	○	●	◐	○	○	High Contrast
Uniform	○	◐	◐	◐	○	Focused
Subtle	○	●	○	○	○	Vibrant
Simple	○	●	◐	○	○	Complex
Calming	○	◐	◐	◐	○	Stimulating
Enlarging	○	○	●	◐	○	Confining

Discussion

The circle sidelight aperture examines the effects of a circle opening in the center of the wall. Similar to the square sidelight aperture, there is a projection of light in the shape of the opening, however the contrast is more subtle and the light is more evenly dispersed. The light reflects throughout the space, but a focus is formed by the light at the center of the space. There is a significant variation in the light meter readings.

Aperture 09 - Square Toplight



Isometric

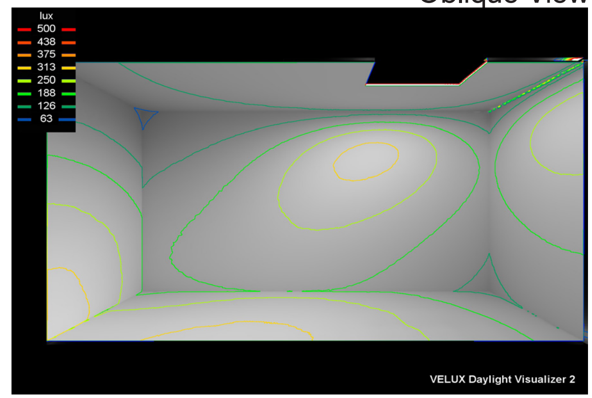
Results

Light Meter Readings in Lux:

306 323 313 270 215 125

Average Illuminations (lx): 260lx

Oblique View



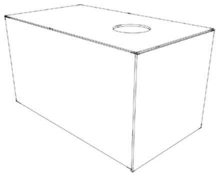
Semantic Scale Rating

Low Contrast	◐	●	◐	○	○	High Contrast
Uniform	◐	●	○	○	○	Focused
Subtle	●	◐	○	○	○	Vibrant
Simple	◐	○	●	○	○	Complex
Calming	◐	●	○	○	○	Stimulating
Enlarging	◐	○	●	○	○	Confining

Discussion

The toplight square aperture examines the effects of an opening within the ceiling. The result is a subtle direction of light and a soft ambient light. The light disperses evenly along the floor. The source of the light generates interest and seem natural. The illumination reading are relatively close and uniform.

Aperture 10 - Circular Toplight



Isometric

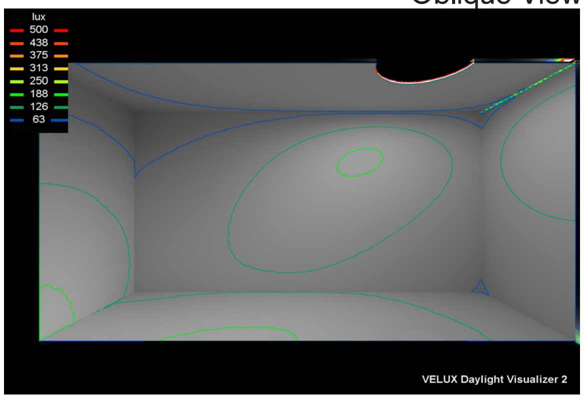
Results

Light Meter Readings in Lux:

184 188 193 177 145 110

Average Illuminations (lx): 166lx

Oblique View



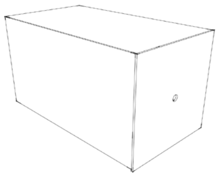
Semantic Scale Rating

Low Contrast	◍	●	○	○	○	High Contrast
Uniform	◍	●	○	○	○	Focused
Subtle	●	◍	○	○	○	Vibrant
Simple	◍	●	○	○	○	Complex
Calming	●	◍	○	○	○	Stimulating
Enlarging	○	○	◍	●	○	Confining

Discussion

The toplight circle aperture examines the effects of an opening within the ceiling. The result is a soft ambient light. The light disperses evenly along the floor. The source of the light generates interest and seem natural. The illumination reading are relatively close and uniform

Aperture 01 – Pin-hole



Isometric

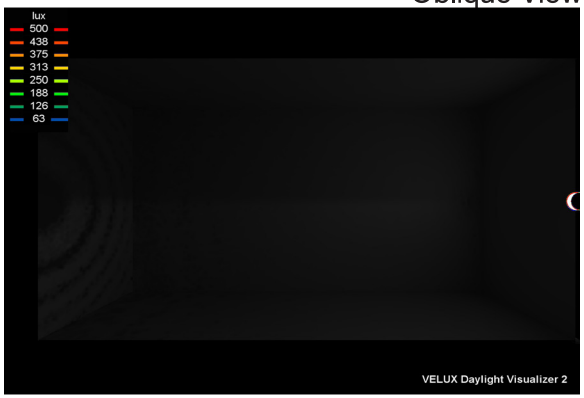
Results

Light Meter Readings in Lux:

1 1 2 3 1 2

Average Illuminations (lx): 2lx

Oblique View



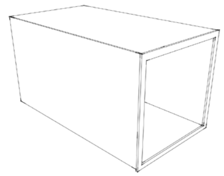
Semantic Scale Rating

Low Contrast	●	○	○	○	○	High Contrast
Uniform	●	○	○	○	○	Focused
Subtle	●	○	○	○	○	Vibrant
Simple	●	○	○	○	○	Complex
Calming	●	○	○	○	○	Stimulating
Enlarging	○	○	○	○	●	Confining

Discussion

The pinhole aperture examines the effects of a single small opening. The result is a single point that animates along the surfaces over the course of the day.

Aperture 02 –Floor to Ceiling



Isometric

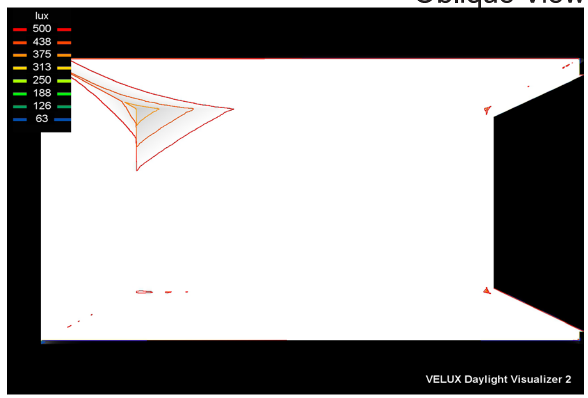
Results

Light Meter Readings in Lux:

507 966 2435 1446 726 439

Average Illuminations (lx): 1085lx

Oblique View



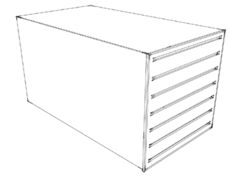
Semantic Scale Rating

Low Contrast	●	○	○	○	○	High Contrast
Uniform	●	◐	○	◐	○	Focused
Subtle	●	○	○	◐	○	Vibrant
Simple	●	○	○	○	○	Complex
Calming	○	◐	○	◐	●	Stimulating
Enlarging	●	○	○	○	○	Confining

Discussion

The floor to ceiling opening examines the effects of an “aperture-less” design. The result is an abundance of uncontrolled natural light. There is no controlled architectural effect. The light conditions are relatively constant from experiment 1A.

Aperture 03 - Horizontal Sidelight



Isometric

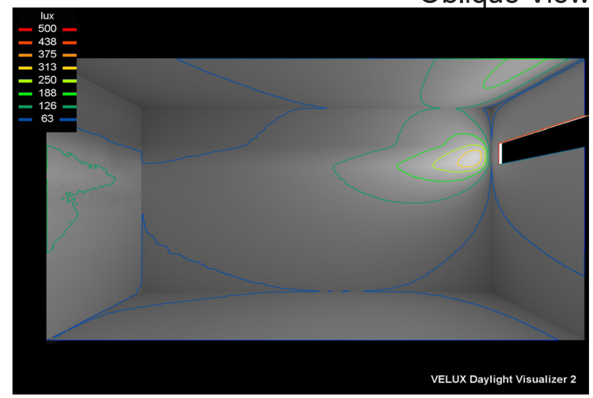
Results

Light Meter Readings in Lux:

102 68 92 56 39 66

Average Illuminations (lx): 71lx

Oblique View



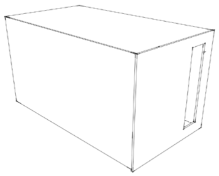
Semantic Scale Rating

Low Contrast	○	○	●	◐	○	High Contrast
Uniform	○	○	○	◐	●	Focused
Subtle	○	○	◐	●	○	Vibrant
Simple	○	◐	◐	○	○	Complex
Calming	○	◐	●	○	○	Stimulating
Enlarging	○	○	○	●	◐	Confining

Discussion

The horizontal aperture examines the effects of a horizontal band opening above sill height. The aperture interacts with the altitude of the sun. In comparison to experiment 1A, light penetrates further into the space, creating architectural effect on the back wall.

Aperture 04 - Vertical Sidelight



Isometric

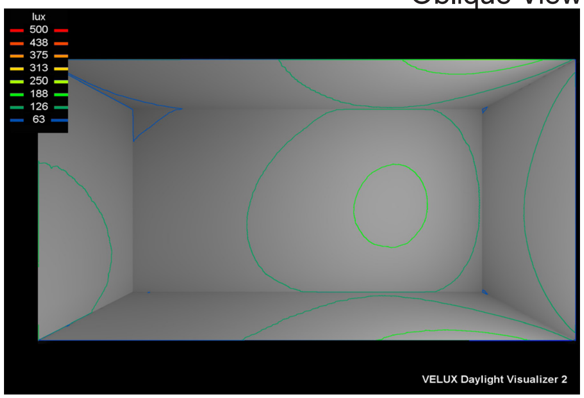
Results

Light Meter Readings in Lux:

113 117 175 528 102 146

Average Illuminations (lx): 137lx

Oblique View



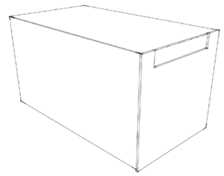
Semantic Scale Rating

	1	2	3	4	5	
Low Contrast	●	○	○	○	○	High Contrast
Uniform	●	◍	○	○	○	Focused
Subtle	●	◍	○	○	○	Vibrant
Simple	●	◍	○	○	○	Complex
Calming	●	◍	○	○	○	Stimulating
Enlarging	○	◍	◍	◍	○	Confining

Discussion

The vertical aperture examines the effects of a vertical sidelight opening from floor to ceiling. The beam of light tracks the position of the sun, marking the surrounding surfaces. There is an apparent interaction between built form and natural light.

Aperture 05 - Upper Sidelight



Isometric

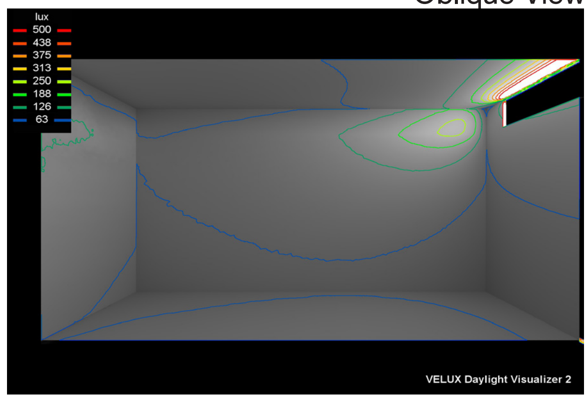
Results

Light Meter Readings in Lux:

106 63 56 66 83 66

Average Illuminations (lx): 76lx

Oblique View



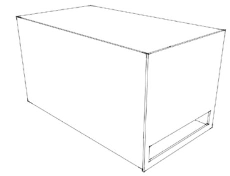
Semantic Scale Rating

	1	2	3	4	5	
Low Contrast	○	○	◍	◍	○	High Contrast
Uniform	○	○	◍	●	◍	Focused
Subtle	○	◍	◍	◍	○	Vibrant
Simple	○	●	○	◍	○	Complex
Calming	○	◍	◍	◍	◍	Stimulating
Enlarging	○	○	○	●	◍	Confining

Discussion

The upper aperture examines the effects of a horizontal band opening at ceiling height. The results is a bleed of light on the adjacent wall and hot-spot on the immediate ceiling. The light penetrates deep and disperses evenly along the floor. There is subtle contrast within the space. The illumination reading are relatively close and uniform.

Aperture 06 - Base Sidelight



Isometric

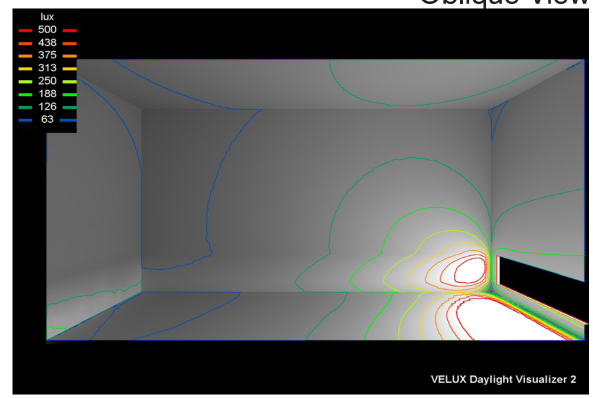
Results

Light Meter Readings in Lux:

73 68 159 256 626 66

Average Illuminations (lx): 208lx

Oblique View



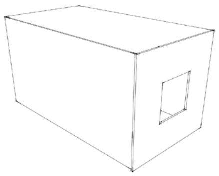
Semantic Scale Rating

	1	2	3	4	5	
Low Contrast	○	○	○	◍	●	High Contrast
Uniform	○	○	○	◍	●	Focused
Subtle	○	○	◍	●	◍	Vibrant
Simple	○	◍	○	●	○	Complex
Calming	○	◍	◍	○	◍	Stimulating
Enlarging	○	○	◍	●	◍	Confining

Discussion

The base aperture examines the effects of a sidelight positioned along the floor of the space. The result is a stripe of light along the floor that reflects into the space. The light is immediately diffused at the floor and gradually decreases further into the space band of light and inverted direction of light creates a surreal environment. The illumination reading are highly diverse.

Aperture 07 - Square Sidelight



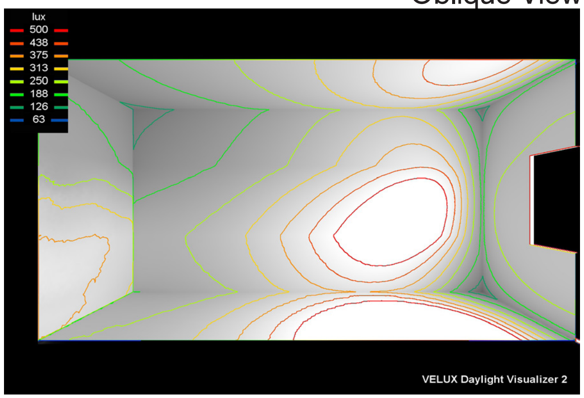
Isometric

Results

Light Meter Readings in Lux:
418 408 760 500 257 485

Average Illuminations (lx): 471lx

Oblique View



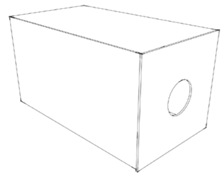
Semantic Scale Rating

	1	2	3	4	5	
Low Contrast	○	◍	●	◍	○	High Contrast
Uniform	○	○	○	●	○	Focused
Subtle	○	○	○	◍	●	Vibrant
Simple	○	○	◍	◍	◍	Complex
Calming	○	○	◍	●	◍	Stimulating
Enlarging	○	●	◍	○	○	Confining

Discussion

The square sidelight aperture examines the effects of a square opening in the center of the wall. The results is a projection of light in the shape of the opening. This heightens the awareness of the aperture. The light reflects throughout the space, but a focus is formed by the light in the center of the space. There is subtle contrast within the space and a significant variation in the light meter readings.

Aperture 08 - Circular Sidelight



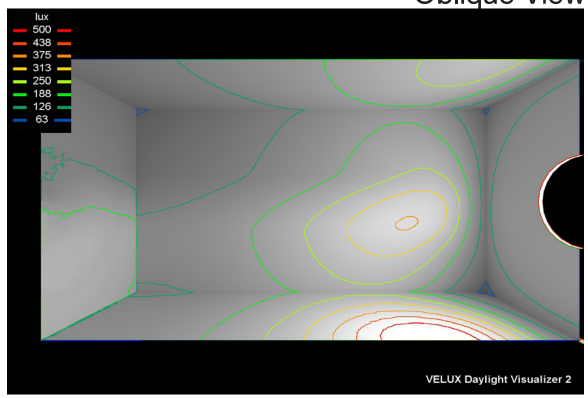
Isometric

Results

Light Meter Readings in Lux:
367 272 593 204 131 480

Average Illuminations (lx): 341lx

Oblique View



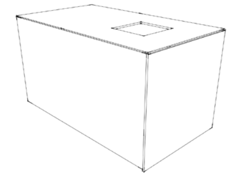
Semantic Scale Rating

	1	2	3	4	5	
Low Contrast	○	●	◍	○	○	High Contrast
Uniform	○	◍	◍	◍	○	Focused
Subtle	○	●	○	○	○	Vibrant
Simple	○	●	◍	○	○	Complex
Calming	○	◍	◍	◍	○	Stimulating
Enlarging	○	○	●	◍	○	Confining

Discussion

The circle sidelight aperture examines the effects of a circle opening in the center of the wall. Similar to the square sidelight aperture, there is a projection of light in the shape of the opening, however the contrast is more subtle and the light is more evenly dispersed. The light reflects throughout the space, but a focus is formed by the light at the center of the space. There is a significant variation in the light meter readings.

Aperture 09 - Square Toplight



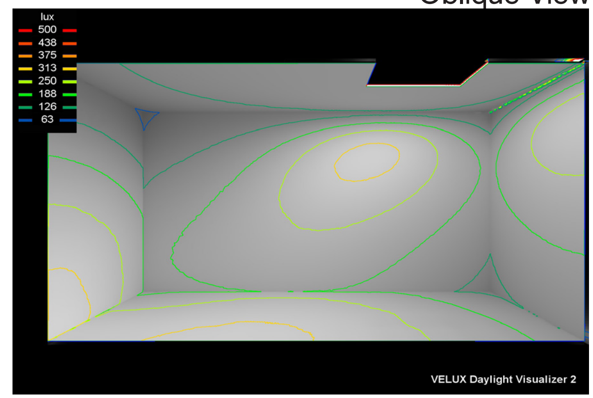
Isometric

Results

Light Meter Readings in Lux:
306 323 313 270 215 125

Average Illuminations (lx): 260lx

Oblique View



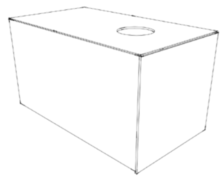
Semantic Scale Rating

	1	2	3	4	5	
Low Contrast	◍	●	◍	○	○	High Contrast
Uniform	◍	●	○	○	○	Focused
Subtle	●	◍	○	○	○	Vibrant
Simple	◍	○	●	○	○	Complex
Calming	◍	●	○	○	○	Stimulating
Enlarging	◍	○	●	○	○	Confining

Discussion

The toplight square aperture examines the effects of an opening within the ceiling. The result is a subtle direction of light and a soft ambient light. The light disperses evenly along the floor. The source of the light generates interest and seem natural. The illumination reading are relatively close and uniform.

Aperture 10 - Circular Toplight



Isometric

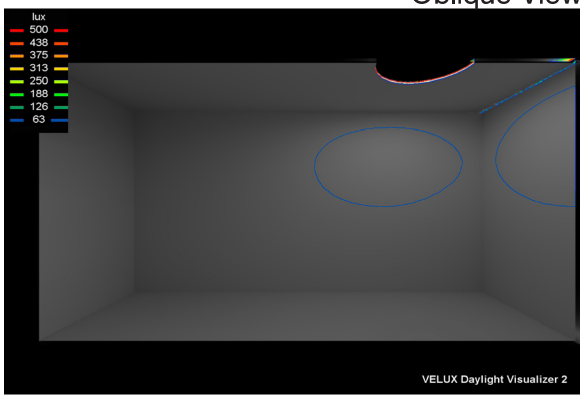
Results

Light Meter Readings in Lux:

28 37 51 63 65 56

Average Illuminations (lx): 50lx

Oblique View



Semantic Scale Rating

Low Contrast	◍	●	○	○	○	High Contrast
Uniform	◍	◍	◍	○	○	Focused
Subtle	◍	●	○	○	○	Vibrant
Simple	◍	●	○	○	○	Complex
Calming	◍	●	○	○	○	Stimulating
Enlarging	○	◍	◍	●	○	Confining

Discussion

The toplight circle aperture examines the effects of an opening within the ceiling. The result is a soft ambient light. The light disperses evenly along the floor. The source of the light generates interest and seem natural. The illumination reading are relatively close and uniform.

Experiment 1 Results

The preceding graphs represent and compare the results from experiment 1A and 1B. The first graph plots the illumination levels across the ground plane for apertures 03-10, from 12pm to 1pm. The graph illustrates how illumination levels and dispersion vary depending on the type of aperture used.

Apertures 03, 05, 09 and 10 generate uniform illumination with averages of 187lx, 139lx, 260lx and 166lx respectively. Apertures 04 and 06 generate a point of high contrast with illumination peaks of 765lx and 1710lx respectively. This peak represents a point of focus that is highly perceptible to changes in exterior conditions. Apertures 07 and 08 generate non-uniform illumination and distinct lighting patterns, connecting the aperture with the space.

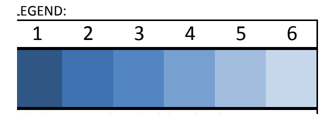
The second graph examines the same series of apertures, yet at a different time of day, changing the lighting parameters. The ratio between the horizontal and vertical illumination presents a unique characteristic for daylighting. When the sun is at a medium to high altitude angle, the vertical illumination amounts to 40% to 60% of the horizontal illumination. When the sun is at a low altitude angle, the vertical illumination predominates, thereby giving objects a different appearance than that produced by a higher sun.

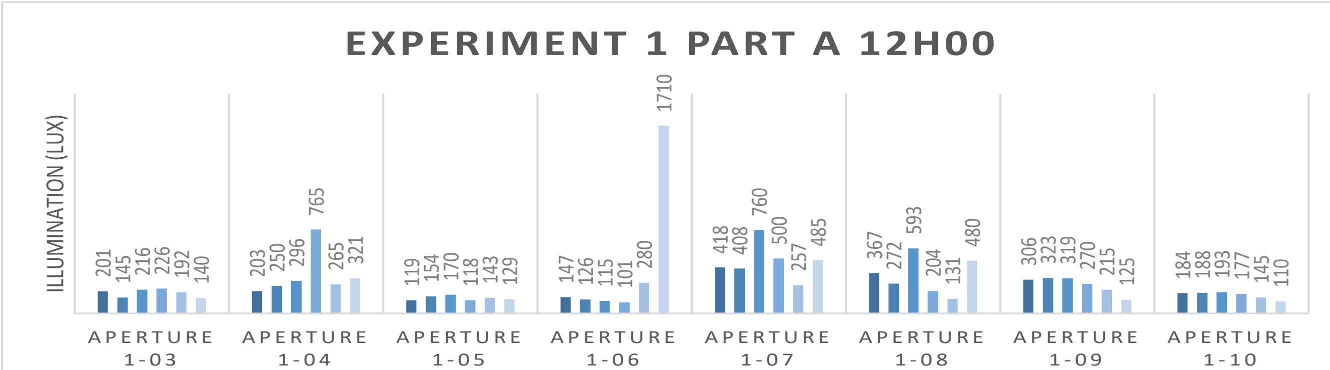
As a result, the characteristics of the aperture greatly affect the illumination of the space. One aperture will be more perceptive to horizontal light while another to vertical light, thus each aperture will perform differently over the period of a day or even year. Subsequently, the result of part A and B were plotted for comparison in the third graph. The graph indicates the dynamism of an aperture as a response to the time of day.

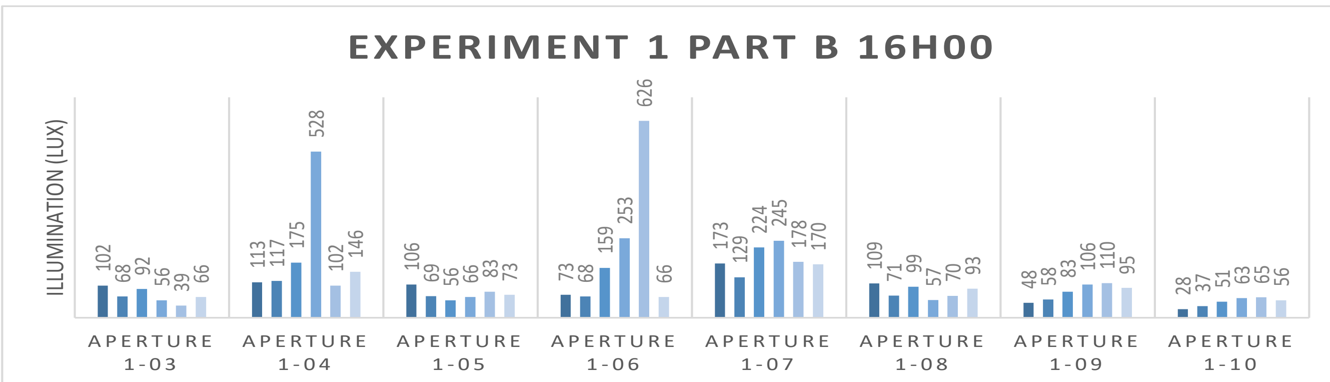
Apertures 06, 07 and 08 generate the most dramatic variance between part A and B, 205lx, 230lx and 258lx respectively. Aperture 09 and 10, the toplight, result in a moderate difference of 177lx and 116lx respectively. Apertures 03 and 04 generate a moderate difference of 116lx and 153lx respectively. Aperture 05 generates the most uniform illumination over the period, with a difference of 63lx.

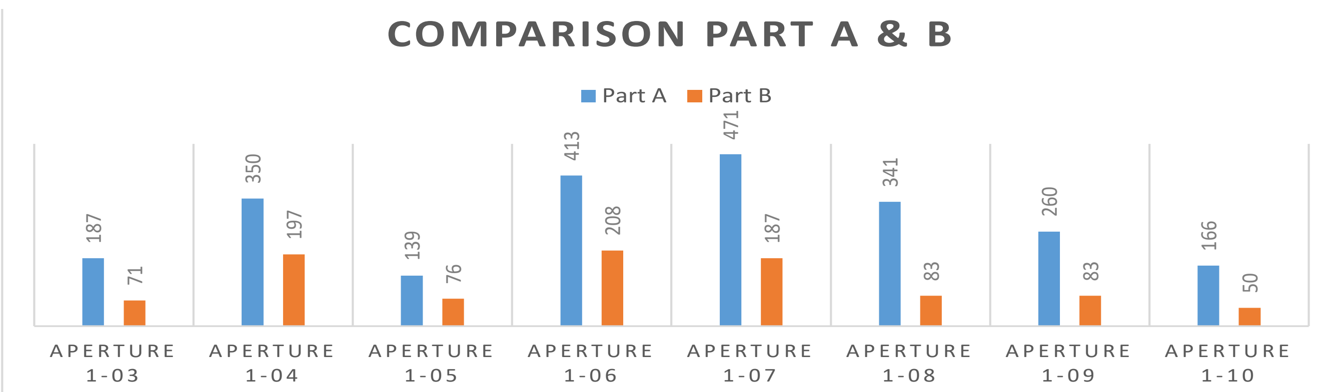
Therefore, the specific features of the apertures used have a dramatic impact on the quality and dispersion of natural light.

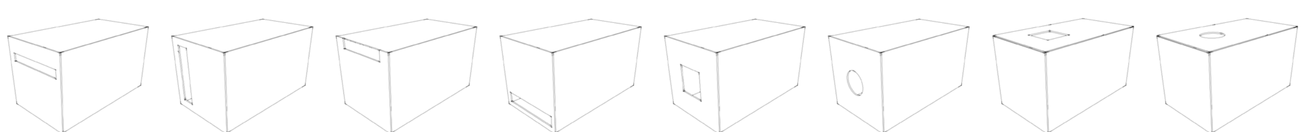
As a result, the characteristics of the aperture greatly affect the illumination of the space. One aperture will be more perceptive to horizontal light while another to vertical light, thus each aperture will perform differently over the period of a day or even year. Subsequently, the result of part A and B were plotted for comparison in the third graph. The graph indicates the dynamism of an aperture as a response to the time of day.


LEGEND:
1 2 3 4 5 6


EXPERIMENT 1 PART A 12H00
ILLUMINATION (LUX)
APERTURE 1-03: 201 145 216 226 192 140
APERTURE 1-04: 203 250 296 765 265 321
APERTURE 1-05: 119 154 170 118 143 129
APERTURE 1-06: 147 126 115 101 280 1710
APERTURE 1-07: 418 408 760 500 257 485
APERTURE 1-08: 367 272 593 204 131 480
APERTURE 1-09: 306 323 319 270 215 125
APERTURE 1-10: 184 188 193 177 145 110


EXPERIMENT 1 PART B 16H00
ILLUMINATION (LUX)
APERTURE 1-03: 102 68 92 56 39 66
APERTURE 1-04: 113 117 175 528 102 146
APERTURE 1-05: 106 69 56 66 83 73
APERTURE 1-06: 73 68 159 253 626 66
APERTURE 1-07: 173 129 224 245 178 170
APERTURE 1-08: 109 71 99 57 70 93
APERTURE 1-09: 48 58 83 106 110 95
APERTURE 1-10: 28 37 51 63 65 56

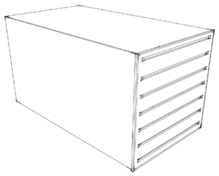

COMPARISON PART A & B
Part A
Part B
APERTURE 1-03: 187 71
APERTURE 1-04: 350 197
APERTURE 1-05: 139 76
APERTURE 1-06: 413 208
APERTURE 1-07: 471 187
APERTURE 1-08: 341 83
APERTURE 1-09: 260 83
APERTURE 1-10: 166 50



Experiment 2

Experiment 2 expands on the first, by exploring the effects of scaling an aperture over a plane. Starting with the prevailing apertures from experiment 1, the aperture is scaled over a plane in order to generate a surface. The dispersion and illumination levels are documented for comparison and analysis. The objective is to discover the distribution effects of the aperture on the interior lighting conditions.

Aperture 01 - Horizontal Array



Isometric

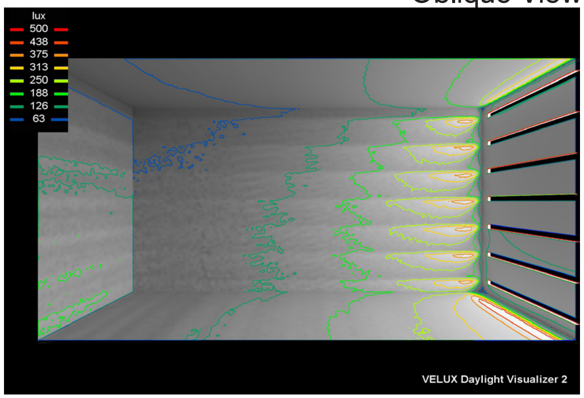
Results

Light Meter Readings in Lux:

87 102 92 500 267 222

Average Illuminations (lx): 212lx

Oblique View



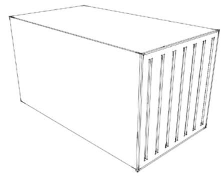
Semantic Scale Rating

Low Contrast	○ ○ ● ◍ ◍	High Contrast
Uniform	○ ○ ◍ ● ◍	Focused
Subtle	○ ○ ◍ ◍ ●	Vibrant
Simple	○ ○ ○ ◍ ●	Complex
Calming	○ ○ ○ ● ◍	Stimulating
Enlarging	○ ◍ ◍ ● ○	Confining

Discussion

The horizontal array aperture examines the effects of horizontal strips from floor to ceiling. The light stretches to the far wall, blending with shadow and creating a subtle animated rhythm and interest. The illumination reading vary throughout the space.

Aperture 02 - Vertical Array



Isometric

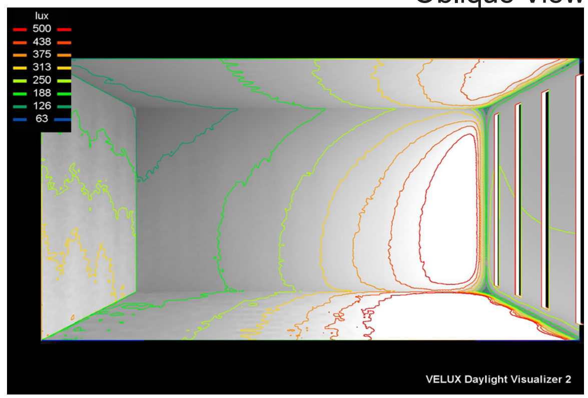
Results

Light Meter Readings in Lux:

194 232 306 382 527 715

Average Illuminations (lx): 393lx

Oblique View



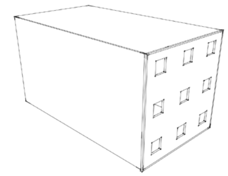
Semantic Scale Rating

Low Contrast	○ ○ ○ ● ◍	High Contrast
Uniform	○ ○ ○ ● ◍	Focused
Subtle	○ ○ ◍ ◍ ●	Vibrant
Simple	○ ○ ○ ◍ ●	Complex
Calming	○ ○ ◍ ◍ ◍	Stimulating
Enlarging	○ ○ ◍ ◍ ◍	Confining

Discussion

The vertical array aperture examines the effects of a vertical strips from floor to ceiling. The result is a series of intense stripes along the floor that emerges into a pattern of light and shadow. Compared to the horizontal strips of the previous experiment, the vertical strips emit more light. This creates more drastic contrast and interest. The illumination readings vary significantly throughout the space.

Aperture 03 - 3x3 Grid Square



Isometric

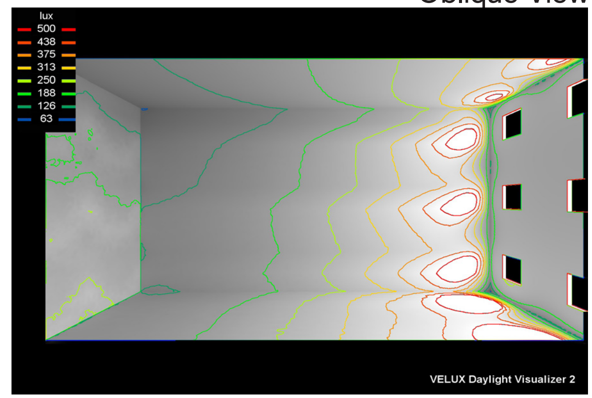
Results

Light Meter Readings in Lux:

155 173 239 317 511 715

Average Illuminations (lx): 352lx

Oblique View



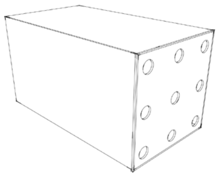
Semantic Scale Rating

Low Contrast	○ ○ ○ ● ◍	High Contrast
Uniform	○ ○ ○ ● ◍	Focused
Subtle	○ ○ ◍ ◍ ●	Vibrant
Simple	○ ○ ○ ◍ ●	Complex
Calming	○ ○ ◍ ◍ ◍	Stimulating
Enlarging	○ ○ ◍ ◍ ◍	Confining

Discussion

The square grid aperture examines the effects of distributing a series openings over a plane. The results is a subtle rhythm of highlights as the light pierces through each opening. The sharp edges of the opening creates a shift contrast between light and shadow. The light bleeds around the edge of the opening, diminishing the contours. The illumination reading vary significantly throughout the space

Aperture 04 - 3x3 Grid Circle



Isometric

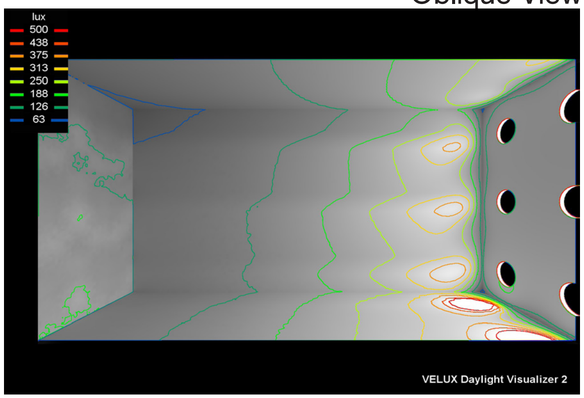
Results

Light Meter Readings in Lux:

107 126 175 250 366 653

Average Illuminations (lx): 280lx

Oblique View



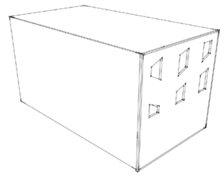
Semantic Scale Rating

Low Contrast	○	○	○	●	◍	High Contrast
Uniform	○	○	◍	●	○	Focused
Subtle	○	○	◍	◍	●	Vibrant
Simple	○	○	○	◍	●	Complex
Calming	○	●	○	◍	○	Stimulating
Enlarging	○	○	●	◍	○	Confining

Discussion

The circle grid aperture examines the effects of distributing a series openings over a plane. The result is similar to that of the previous experiment with the exception that the light is softer and more evenly dispersed. The illumination reading vary throughout the space

Aperture 05 - Upper Trapezoid Array



Isometric

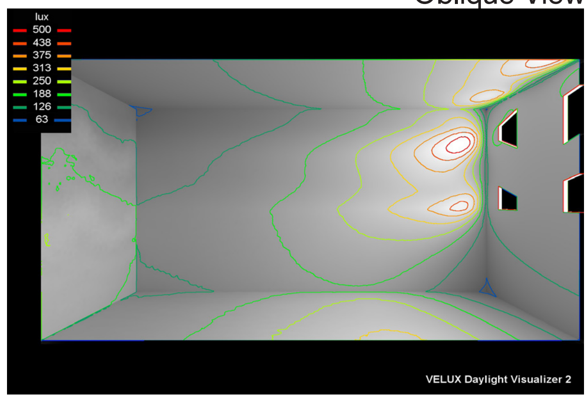
Results

Light Meter Readings in Lux:

156 186 279 331 235 129

Average Illuminations (lx): 219lx

Oblique View



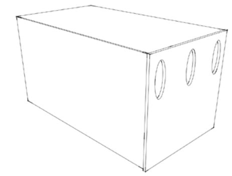
Semantic Scale Rating

Low Contrast	○	○	●	○	◍	High Contrast
Uniform	○	○	◍	●	○	Focused
Subtle	○	◍	◍	◍	○	Vibrant
Simple	○	○	◍	●	○	Complex
Calming	○	◍	◍	●	○	Stimulating
Enlarging	○	◍	●	◍	○	Confining

Discussion

The trapezoid array aperture examines the effects of skewing the openings. The intention is to randomize the diffusion of light. The results are unevenly dispersion of light. The openings were shifted above sill height, resulting in a softer deeper diffusion, as observed in previous experiments. The light penetrates to the back wall where it adds subtle pattern and interest. The illumination reading vary slightly throughout the space.

Aperture 06 - Upper Ellipse Array



Isometric

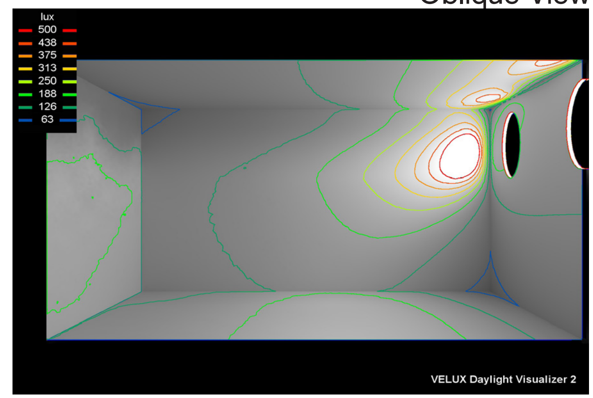
Results

Light Meter Readings in Lux:

140 155 208 241 172 111

Average Illuminations (lx): 171lx

Oblique View



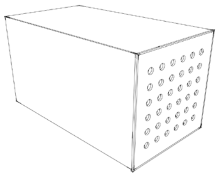
Semantic Scale Rating

Low Contrast	○	○	○	◍	●	High Contrast
Uniform	○	○	○	●	◍	Focused
Subtle	○	○	○	◍	●	Vibrant
Simple	○	○	◍	●	○	Complex
Calming	○	○	◍	●	◍	Stimulating
Enlarging	○	○	●	◍	◍	Confining

Discussion

The ellipse array aperture examines the effects of a converging the circle grid into an ellipse, focused towards the upper section of the wall. The result is a diluted dispersion of light. A glow appears to radiate from the center of the space. The shadows are soft and the light is evenly dispersed. The illumination readings remain constant throughout the space.

Aperture 07 - 6x6 Grid Circle



Isometric

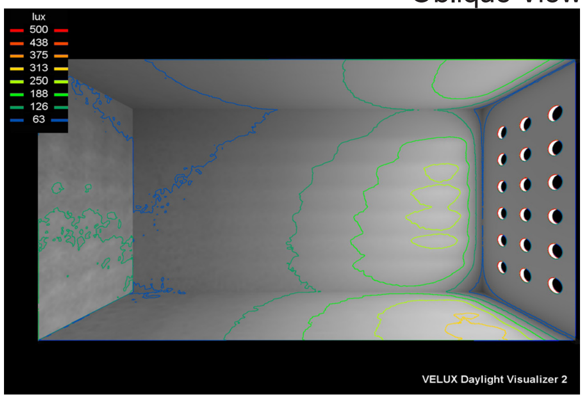
Results

Light Meter Readings in Lux:

84 87 127 216 314 245

Average Illuminations (lx): 179lx

Oblique View



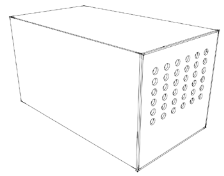
Semantic Scale Rating

Low Contrast	○	●	◉	○	○	High Contrast
Uniform	○	◉	●	○	○	Focused
Subtle	○	◉	◉	◉	○	Vibrant
Simple	○	○	○	◉	◉	Complex
Calming	○	●	◉	○	○	Stimulating
Enlarging	○	◉	○	◉	○	Confining

Discussion

The 6x6 circle grid aperture further examines the effects breaking up and distributing the openings on a plan. The apertures appear to shoot rays horizontally, projecting onto the rear wall; the effect is very subtle. The results is a subtle rhythm and atmosphere created by the blend of shadow and light. The light penetrates to the back wall where is adds pattern and interest. The illumination fade gradually towards the rear of the space.

Aperture 08 - 6x6 Grid Circle Shifted



Isometric

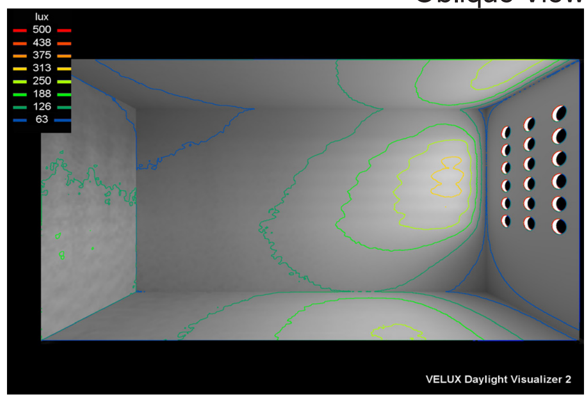
Results

Light Meter Readings in Lux:

108 127 194 251 226 95

Average Illuminations (lx): 167lx

Oblique View



Semantic Scale Rating

Low Contrast	○	◉	◉	◉	○	High Contrast
Uniform	○	○	◉	◉	○	Focused
Subtle	○	◉	◉	◉	○	Vibrant
Simple	○	○	◉	◉	○	Complex
Calming	○	◉	◉	◉	○	Stimulating
Enlarging	○	◉	◉	◉	○	Confining

Discussion

The shifted 6x6 circle grid aperture examines the effects taking the previous experiment and shifting the openings. Light is more evenly dispersed. The apertures appear to shoot rays horizontally, projecting onto the rear wall; the effect is very subtle. The light penetrates to the back wall where is adds pattern and interest. The illumination reading are relatively close and uniform.

Experiment 2 Results

The preceding graph compares the results from Experiment 2. The graph plots the illumination levels across the ground plane for each aperture, from 12pm to 1pm. The illumination levels vary, depending on the character of the aperture.

Apertures 01 and 02 identify a difference in illumination levels and dispersion depending on the orientation. Average illumination for apertures 01 and 02 are 212lx and 392lx respectively.

Apertures 03 and 04 identify a difference in illumination levels dependent on the shape of the aperture.

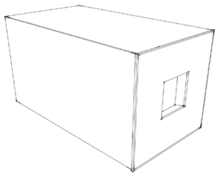
Aperture 05 and 06 identify the effect of concentrating the apertures in the upper portion of the surface. In comparison to apertures 03 and 04, the average illumination levels are less but still diverse.

Apertures 07 and 08 explore the effect of smaller openings distributed over the surface and concentrated within the upper portion, respectively. The illumination levels were slightly lower with aperture 08 than with aperture 07.

Experiment 3

Experiment 3 expands on the first two experiments by exploring the effects of extruding an aperture into a form. Dispersion and illumination levels are documented for comparison and analysis . The objective is to discover the distribution effects of the aperture on the interior lighting conditions.

Aperture 01 - Square Tapered Out



Isometric

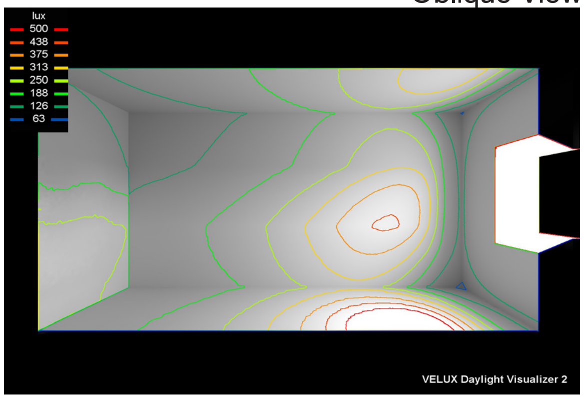
Results

Light Meter Readings in Lux:

177 210 349 579 563 268

Average Illuminations (lx): 358lx

Oblique View



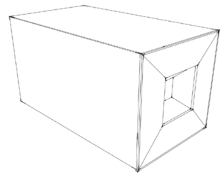
Semantic Scale Rating

Low Contrast	○	○	●	○	○	High Contrast
Uniform	○	○	●	○	○	Focused
Subtle	○	◍	◍	◍	○	Vibrant
Simple	○	◍	●	○	○	Complex
Calming	○	●	◍	◍	○	Stimulating
Enlarging	◍	◍	◍	○	○	Confining

Discussion

The square tapered out aperture examines the effects of focuses light into a space. The aperture emits a small opening on the exterior and opens up on the interior, similar to a luminaire. The aperture radiates light in all directions. The light reflects inside the aperture, pushing light into the space. The illumination fades gradually towards the rear of the space.

Aperture 02 - Square Tapered In



Isometric

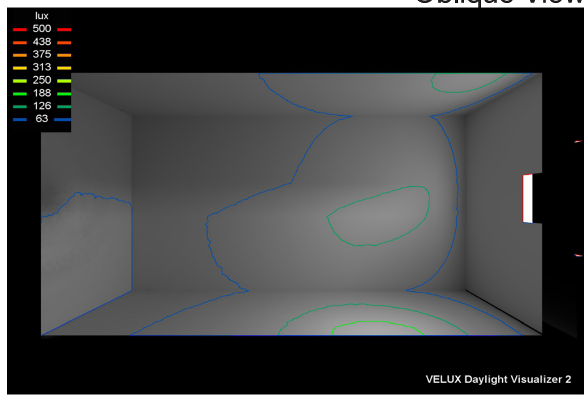
Results

Light Meter Readings in Lux:

59 77 153 216 105 63

Average Illuminations (lx): 112lx

Oblique View



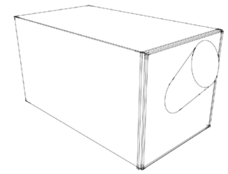
Semantic Scale Rating

Low Contrast	○	●	◍	○	○	High Contrast
Uniform	○	◍	●	○	○	Focused
Subtle	◍	◍	○	◍	○	Vibrant
Simple	○	◍	◍	◍	○	Complex
Calming	◍	●	○	○	○	Stimulating
Enlarging	○	○	◍	●	○	Confining

Discussion

The square tapered in aperture examines the effects of funneling light into a space. The aperture emits a large opening on the exterior and closes up on the interior. The aperture reflects light prior to entering the space, resulting in less illumination than the previous experiment. The illumination fade gradually towards the rear of the space.

Aperture 03 - Circular Cannon



Isometric

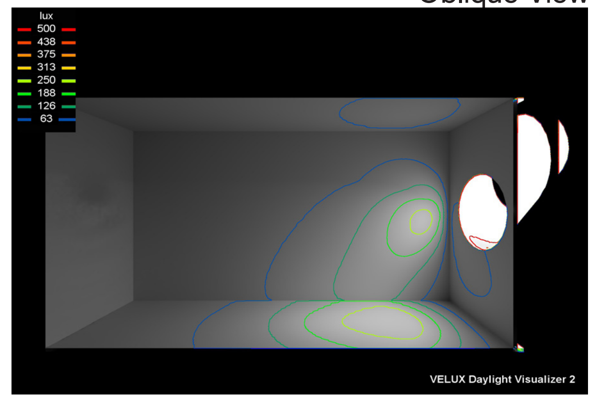
Results

Light Meter Readings in Lux:

39 49 89 166 242 94

Average Illuminations (lx): 113lx

Oblique View



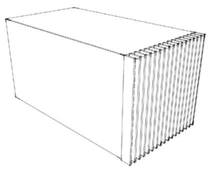
Semantic Scale Rating

Low Contrast	○	○	◍	◍	◍	High Contrast
Uniform	○	○	○	●	◍	Focused
Subtle	○	◍	○	◍	○	Vibrant
Simple	○	◍	◍	◍	○	Complex
Calming	○	◍	◍	○	○	Stimulating
Enlarging	○	○	◍	●	○	Confining

Discussion

The circular cannon aperture further examines a light cannon by Le Corbusier. Light is captured, reflected down a cylindrical "cannon" and fired into the space. The illumination area is focused and directed.

Aperture 04 - Vertical Lattice



Isometric

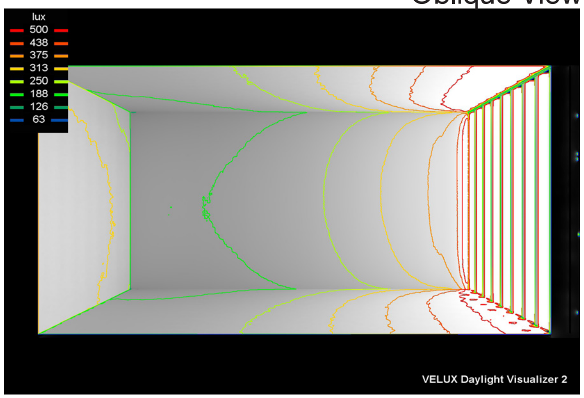
Results

Light Meter Readings in Lux:

484 504 590 778 696 1013

Average Illuminations (lx): 723lx

Oblique View



Semantic Scale Rating

Low Contrast	○	●	○	○	○	High Contrast
Uniform	○	●	○	○	○	Focused
Subtle	○	○	◉	●	○	Vibrant
Simple	○	○	◉	●	○	Complex
Calming	○	○	◉	●	○	Stimulating
Enlarging	●	◉	○	○	○	Confining

Discussion

The vertical lattice aperture further examines the effects a vertical array. The array is extruded to add more volume and break up the direct light. Light is more evenly dispersed. The light penetrates to the back wall where is adds pattern and interest. The illumination gradually fades towards the rear of the space.

Experiment 3 Results

The preceding graph compares the results from experiment 3. The graph plots the illumination levels across the ground plane for each aperture, from 12pm to 1pm.

Apertures 01 and 02 explore the effects of a square aperture tapered inwards and outwards. The illumination levels are effected by the orientation of the taper. Aperture 01 permits more light at the exterior which reflects through the aperture. As a result, the illumination levels are higher than aperture 02 and more diverse than the square aperture of experiment 1. Aperture 02 concentrates light, funneling the light through a smaller opening, resulting in less illumination and more focus.

Aperture 03 is a representation of a “canon de lumière” found in La Tourette by Le Corbusier.

The aperture is oriented towards the sun and is expected to shoot light through the aperture into the space. Most of the light from the experiment reflects within the aperture, resulting in a subtle and soft dispersion of light, similar to the toplights of experiment 1.

Aperture 04 explores the effects of extruding vertical strips, similar to the aperture 02 from experiment 2. In comparison, aperture 04 permits a higher illumination and disperses the light more evenly, while still being relatively diverse. This aperture generates an interesting level of contracts and shall be further explored.