Passive Spaces for Active Learners

"A palette of classroom spaces based on daylighting"

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Abstract

Passive Spaces for Active Learners

"A Palette of Classroom Spaces based on Daylighting"

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The school buildings and their learning environments have been invariable over a period of time and they do not support the 21st century building pedagogy. The contemporary design of the buildings do not respond to the present needs. Through this thesis I identified some design variables that helped to design different classroom typologies. Since classroom lighting plays a particularly critical role in student performance all these typologies are based on daylighting. Appropriate lighting is one of the most critical performance attributes of the learning environment.

INTRODUCTION

"As population grows and finite raw materials are consumed in ever greater numbers, we must find better ways to manage our planet's resources and to preserve its ecosystems. In the process, we must develop methods of instructing future generations about energy conservation." [1]

"Strategies to reduce the negative impact of human activity on the natural world begin with education. School leaders can be instrumental in expanding public awareness of sustainability by providing students positive examples of the cohabitation of natural and built environments." [2]

High performance school buildings serve as models for teaching sustainable principals through integrated and project based learning. "*These schools not only provide safer and healthier learning spaces but also reduce student absenteeism. They create an opportunity to use the building as a teaching tool and to facilitate students' interaction with environment while lowering the operational and life cycle costs significantly."* [3]

A built environment that provides appropriate lighting, sound, temperature, cleanliness, and air quality helps students learn better. Improving these variables can also reduce the energy use. A good lighting system includes a combination of Daylighting and electric lighting systems. Together these elements help in reducing the visual strain and also provide good quality lighting to users.

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1. Zebing Engineering and Construction Solutions / http://zebingsolutions.com/zebing-energy-management.html

2. *50% Advanced energy Design Guide for K-12 School Buildings Pg 16 / Paragraph 2*

3. *50% Advanced energy Design Guide for K-12 School Buildings Pg 16 / Paragraph 3*

Daylighting is an important strategy for achieving energy savings as it requires little or no electrical lighting. The High Performance School buildings help the students understand a variety of disciplines, and make them conscious about their role in making this planet more green and sustainable by acting as a teaching tool that demonstrates the ideal practices to achieve these goals.

Many schools on an average spend more money on energy costs each year than on school supplies. By using energy efficiently schools can lower their energy consumption and save millions of dollars which can be redirected towards improving facilities and providing better educational resources.

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CHAPTER I

PROBLEM STATEMENT

The school buildings and their learning environments have been invariable over a period of time and they do not support the 21st century building pedagogy. The contemporary design of the buildings do not respond to the present needs.

PROJECT RATIONALE

"*The majority of classrooms in use today were built for traditional, "stand-and-deliver, sit-and-listen" pedagogies in a passive learning setting*."[4] The infrastructure of the schools and their learning environments have remained static over a period of time and they need to move away from the conventional "Chalk and Talk" learning pedagogies. The school buildings are not able to adapt to the dynamic learning approaches and accommodate to changing learning patterns while continuing to inspire students.

The design of the schools should be a reflection of the advancement in information and technology. Therefore it is important to create spaces where the physical environment will have as much impact on the overall development of the students as the digital technologies on the new learning patterns. This would result in creating a healthy and sustainable environment that is integrated with the dynamic learning models.

As a designer my position will be to create a learning environment that resonates with the ever-changing learning strategies. Through this research paper I shall propose design patterns that

4. Steelcase : Learning Spaces - classrooms https://www.steelcase.com/spaces-inspiration/active-learning-spaces-classrooms/#research-insights_observations

will be an amalgamation of various building and High performance strategies that will resonate with these dynamic patterns and technologies along with environmental factors that will enhance learning outcomes.

My project will be to create patterns of classroom spaces that can thrive with the changing learning models. To design a classroom that teaches. My aim will be to create an appropriate system that integrates with the dynamic 21st century school learning models. A design that will be built to foster learning anytime and everywhere through both purposeful and unscheduled social interaction.

RESEARCH QUESTIONS

My research questions were based on the growing need for designing new learning centers which can adapt to the 21st century learning models

- How can schools adapt to and integrate with changing learning models?
- How does a conducive environment enhance the thinking capabilities of students?
- Does the school infrastructure and environment impact student learning outcomes?

POSITION

1) Create Schools that can "Learn": Stuart Brand's notion about making buildings that can adapt and change to accommodate new needs.

2) To find creative design solutions to the Classroom space to make it a High Performance learning environment and energy efficient building.

THESIS OVERVIEW

"*PASSIVE SPACES FOR ACTIVE LEARNING*"

"*The United States has over $2 trillion of net worth tied up in its school facilities, making it the country's single largest educational investment.*" [5] "*School districts throughout the United States put $12.9 billion worth of construction in place during 2015. Out of which $6.1 billion went for entirely new buildings, $3.7 billion was used to add to existing buildings and $3.1 billion went into maintenance of existing buildings.*"[6] The average age of the schools in most districts is between thirty and fifty years.

The conventional school buildings are struggling to facilitate the modern methods of teaching and learning, in turn causing a hindrance towards the delivery of a true 21st century education.

The qualitative study in this paper examines the myriad factors that impact the overall learning experience of the students. It specifically addresses daylighting quality of the classroom / learning space and how it needs to be adaptive to the changing learning models. It also discuses different patterns of performance and their impact on the learning outcomes of the students and teachers.

The precedent studies included projects which are similar in program and also deal with the same issues and have answered to these problems through architectural solutions. The data collected, documents and reports have yielded valuable information about the design and arrangement of Schools and interactions among students and adults in a 21st century learning environment.
The review of the literature revealed that the original school designs were based on the 'chalk and

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5. *Blueprint for Tomorrow by Prakash Nair / Pg 1 / Paragraph 1*

6. *The State of School Construction by Paul Abramson : A look at what happened in 2015 / Pg 2 / Paragraph 2*

duster' pedagogies where the classroom layout was designed around the teacher. It was felt that the students should always be under the teacher's supervision and no emphasis was given to student as an individual or their interactions.

Whereas *"The physical environment in which learning occurs should be designed and constructed around powerful theories of learning, rather than requiring that our theories of learning be adapted to fit into obsolete structures."*[7]

With this thesis I shall make an earnest attempt to find architectural solutions to numerous rising issues of 21st century learning classroom patterns. Through various precedents and literature review I shall explore the hidden messages that our school facilities and classrooms convey and advocate for the alignment of the design of places in which we teach and learn with 21st learning goals.

7. *Richard F. Elmore, professor emeritus of educational leadership, Harvard Graduate School of Education / http://hepg.org/hep-home/books/blueprint-for-tomorrow*

CHAPTER II

LITERATURE REVIEW | **BUILDINGS AS PEDAGOGY**

Pedagogy may be defined as an art of educating through building design. "*It is paradoxical that buildings on college and university campuses, places of intellect, characteristically show so little thought, imagination, sense of place, ecological awareness, and relation to any larger pedagogical intent.*"[8] ~ David Orr

We spend 90% of our time in the buildings which are responsible for almost 40% of all the carbon emissions.[9] Therefor it becomes important to design buildings that perform better cause that will not only address the environmental issues but also act as a pedagogical tool that would educate us how to live more a sustainable lifestyle. These high performing buildings may change our attitudes and perceptions about sustainability and built environment tremendously.

Soon the environmental concerns will be on a rise, where every individual shall be conscious about the energy, water, materials, and carbon emissions; and how they are connected to and impacting human health and our planet. So, What better place to start cultivating these ideas and concepts then a school environment where students spend most of their growing years. The time spent by a student in a school environment is enough time for the schools setting, physical appearance and overall design to impact and influence a student's life.

David Orr coined the term "***Architecture as Pedagogy***" to describe this concept, specifically the social and environmental lessons we can learn from our buildings. Rocky Rowhedder also expanded on this idea by stating that buildings have tremendous pedagogical power, and it is up to our

8. David Orr, "ARCHITECTURE AS PEDAGOGY," 1994

9. When Buildings Compete, We All Win *by Administrator Gina McCarthy*

academic institutions to transform it into teaching tools for sustainability (Rohwedder 1998). He also argues that creating sustainable buildings allows an institution to demonstrate civic responsibility and convey an important message to the students that the educators are investing in their future. [10]

"*Environment as the Integrating Context for learning designates pedagogy that employs natural and socio-cultural environments as the context for learning while taking into account the "best practices" of successful educators."*[11] Research suggests that "*modeling sustainability within the school itself is one of the most effective ways to teach students about sustainability*."[12] For instance if the mechanical equipment for heating and cooling systems are made visible, students can observe and learn how it works.

10. *Rohwedder 2004*

11. Closing the Achievement Gap*: Using the Environment as an Integrating Context for Learning. http://files.eric.ed.gov/fulltext/ED428942.pdf*

12. Teaching Through Modeling: Four Schools' Experiences in Sustainability Education by *Higgs and McMillan*

"*The physical environment in which learning occurs should be designed and constructed around powerful theories of learning, rather than requiring that our theories of learning be adapted to fit into obsolete structures.*"[13]

"*Billions of dollars are being spent each year to retrofit, renovate, and build schools in America, and yet these "new" designs are based on outmoded concepts, ignore vital ecological principles, and fail to include client input. This educational system then is linked to the design of the built, natural, and cultural environment so that the resultant architecture can act as a three-dimensional textbook*." [14]

Schools play a very important role in the overall development of a child. The design of the schools have remain static over time. "*The majority of classrooms in use today were built for traditional, "stand-and-deliver, sit-and-listen" pedagogies in a passive learning setting.*" [15] In last few decades there have been a major advancement in science and technology. School shave started to adopt to innovative curricula and teaching strategies. "*To fully capitalize on the benefits of active learning, physical space must support and enhance the pedagogies employed in the classroom. Institutions should consider how flexibility and variety work with pedagogy, technology and space to support how learning happens in active learning classrooms*." [16]

Numerous studies on the built environment of the classroom space has shown that the class rooms should move away from the traditional settings of rows of fixed tablet chairs and a lectern. Instead the classroom should engage and inspire by putting control of the learning space in the hands of

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13. *Blueprint for Tomorrow by Prakash Nair*
14. *Programming and Design of Public Schools within the Context of Community by AnnTaylor*
15. *Steelcase : Learning Spaces - Classrooms*
16. *Washington State School Protocol : Criterion for High Performance Schools 2010 edition*

students and instructors.

Educating through design bridges the gap between thinking and doing, while at the same time increasing the connections between schools and society. A high-performance school building is a healthy, comfortable, safe and secure, adaptable, easy to maintain, and resource efficient.

The performance of students is a function of following variables :

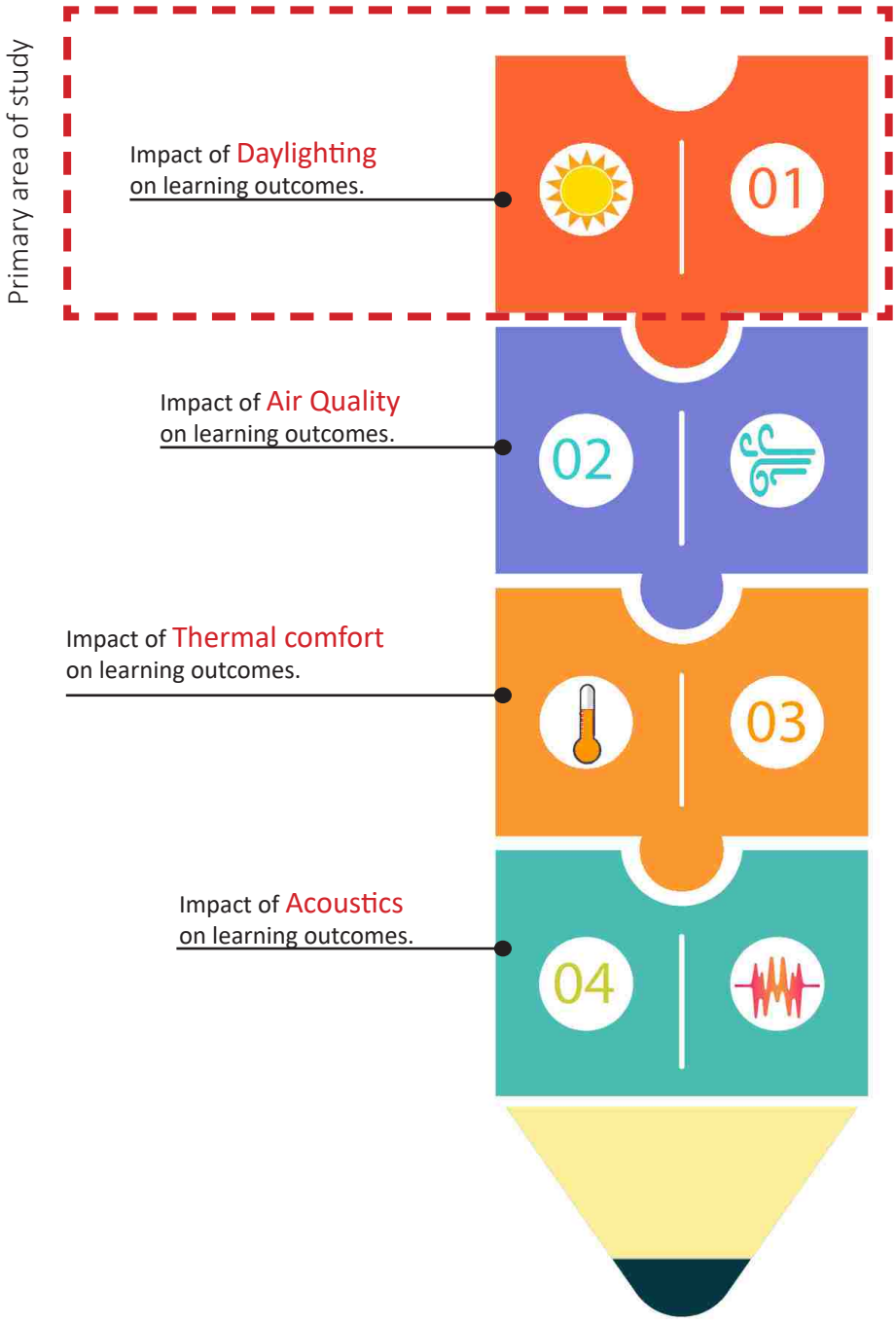

Image a: Image displaying various Patterns of Performance

Daylighting plays a very important role in the design of the classroom space. Classroom lighting plays a particularly critical role in student performance. Appropriate lighting improves concentration, reduces off-task behavior, and plays a significant role in students' achievement. "*Until the 1950s, natural light was the predominant means of illuminating most school spaces, but as electric power costs declined, so too did the amount of daylighting used in schools.*"[17]

Statistical studies involving 21,000 students in three states, by the National Renewable Energy laboratory, revealed that students perform better in Day-lit classrooms as well as indicate health benefits of daylighting. Studies also show that daylighting in schools may significantly increase students' test scores and promote better health and physical development and can be attained without an increase in school construction or maintenance costs.

Daylighting also helps in reducing the heating, ventilation and air conditioning systems which in turn reduce the noise levels of classrooms, thus enhancing the learning environment. Scientists who study the "neuroscience of learning" are finding that certain lighting, acoustics, and spatial relationships support or hinder the learning process.

Appropriate lighting is one of the most critical performance attributes of the learning environment. Strongly related to both color and energy performance, lighting in a 21st-century classroom draws upon natural and electric light sources and requires special attention to the varied activities being lit, the use of technology, orientation, and time of year.

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17. *Acoustics and Daylighting By Marc Spector , May 1st, 2012*

With activities ranging from napping to detailed project-based work and learning media ranging from finger paint to digital audio-visual displays, lighting in the classroom needs to be adjustable and flexible to the task. Considering the varied activities that may occur simultaneously within a classroom, lighting may also need to vary across the room. Classrooms can be designed that present the teacher with opportunities to use natural light at the windows.

One major challenge is to provide glare-free natural light supplemented by switchable and dimmable electric lighting. Different strategies may be applied such as tall windows with shades, and depending upon the orientation, light shelves can help provide glare-free natural light deep into a classroom.

"A day lit space also fosters the feeling of security and trust that is critical to the development of a student." [18] It was also observed that *"Students in daylit classrooms could save up-to one month of instruction time in the reading and math curriculum that could be used for other areas of learning."* [19]

"Daylighting forms the cornerstone of sustainable, high performance design for schools. Affecting individuals on both conscious and subconscious levels, it provides light to see the work environment, a natural rhythm that determines the cycles of days and seasons, and biological stimulation for hormones that regulate body systems and moods." [20]

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18. Built environment and Children's development *by Thomas G david and Carol Simon Weinstein / Pg 10*

19. Daylighting in Schools *: An investigation into the relationship between daylighting and human performance*

20. Daylighting and Fenestration Design. *http://www.lightingassociates.org/i/u/2127806/f/tech_sheets/daylighting_and_fenestration_design.pdf*

There is a growing body of work linking educational achievement and student performance to the quality of air they breathe in schools. "T*he U.S. General Accounting Office has found that fifteen thousand schools suffer from poor IAQ, affecting more than eight million children or one in five children in America's schools. The symptoms include irritated eyes, nose and throat, upper respiratory infections, nausea, dizziness, headaches and fatigue, or sleepiness—have collectively been referred to as "sick building syndrome*". [21]

These problems are stem from the poor infrastructure design which is not adequate anymore. The poor indoor air quality impacts the students and teachers directly as it makes them sick which in turn impacts their performance and increases student and teacher absenteeism.

"*American children miss more than ten million school days each year because of asthma exacerbated by poor Indoor Air Quality.*"[22] Temperature and humidity also affect the indoor air quality significantly as their levels can promote or inhibit the presence of bacteria and mold.

"*Schools also need good ventilation because children breathe a greater volume of air in proportion to their body weight than adults do and because schools have much less floor space per person than found in most office buildings*" [23]

If a building lacks good ventilation, carbon dioxide levels can elevate to unacceptable levels and cause headaches, drowsiness, and the inability to concentrate ensue.

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21. *National Clearinghouse for Educational Facilities http://www.ncef.org/pubs/outcomes.pdf*

22. *The American Lung Association (ALA) IAQ (ALA 2002, EPA 2000)*

23. *(Kennedy 2001, McGovern 1998, Moore 1998),* (Crawford 1998)

PATTERNS OF PERFORMANCE | **IMPACT OF THERMAL COMFORT**

"*Research shows that even within commonly acceptable temperature spans, there are specific ranges that increase individual performance. It is not feasible, however, to provide every student in a common space with the temperature or humidity that best suits him or her*." [24]

Thermal factors may seriously degrade teachers' abilities to teach and may also affect their morale. It has been found that problems caused by working conditions may result in higher absenteeism, reduced effort, lower effectiveness in the classroom, low morale, and reduced job satisfaction.

PATTERNS OF PERFORMANCE | **IMPACT OF ACOUSTICS**

Good acoustics are fundamental to good academic performance. Excessive noise not only causes distraction but also increases stress levels in students. High levels of background noise adversely affect learning environments, particularly for young children, who require optimal conditions for hearing and comprehension. Poor acoustics are a barrier to children with a hearing loss. Since children have smaller vocabularies they are less able to fill in words not heard clearly.

"*The United States Access Board, which supports ADA implementation, recognizes that poor acoustics also have a negative impact on hearing-impaired students.*"[25] The ability to hear and to be heard is one of the most critical performance criterion of a successful learning environment.

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24. National Clearinghouse for Educational Facilities , *http://www.ncef.org/pubs/outcomes.pdf*

25. WBDG-A program of the National Institute of Building Sciences , *https://www.wbdg.org/building-types/education-facilities/elementary-school*

Exterior noise is often the most difficult to control and is a more challenging issue on urban sites, requiring greater performance from window assemblies, in particular.

Proper acoustics within and between classrooms will likely become even more critical over time as the use of audio-visual equipment with multimedia capabilities—such as interactive white-boards— continues to proliferate and more active learning pedagogies are employed.

PRECEDENT STUDY | **HIGH PERFORMANCE CLASSROOM**, Mt. Angel Abbey's Academic Center

Location : Portland, Oregan

Architects : SRG Architects

The Mount Angel Academic Center is a collaborative design of a high performance building that features excellent building envelope design combined with extensive daylight combined with extensive daylighting and comprehensive natural ventilation cooling. The building is developed with an integrated natural ventilation system that does not require any mechanical cooling. The energy consumption of the facility is 60% lower than the current Oregon Energy Code.

Image b: *High Performance Classroom at Mt. Angel Abbey's Academic Center*

The classrooms of the center have a unique design to improve the quality of the Daylight. Daylighting is achieved using a large centrally located skylight, a sloped ceiling, and a reflector hanging

below the skylight. These skylights have louvers between the glass plates that are controlled by light sensors.

The louvers automatically adjust to maintain a pre-set light level in the classroom. An aluminum metal fabricated reflector hanging below the skylight reflects daylight onto the sloped ceiling that reflects the light back down into the room. The very center of the reflector is completely open. This configuration (of skylight with controls, reflector, sloped ceiling) provides a uniform light distribution by allowing some light to pass directly into the room while reflecting some of the light from the skylight onto the ceiling that is then reflected into the room. Because of the lighting configuration, the light levels on the walls are approximately the same as the lighting levels on the floor.

Image c: *High Performance Classroom at Mt. Angel Abbey's Academic Center*

26. *Source : Solarc Energy Group / https://www.solarcenergygroup.com/mt-angel-abbey-academic-center*

Location : Bainbridge Island, Washington

Architects : Mahlum Architects

The Wilkes Elementary School is located on the Bainbridge Island. *"Carved into the hillside and nestled at the base of the forested backdrop, bars of classrooms alternate with exterior courtyards to provide daylight to all learning spaces."*[27]

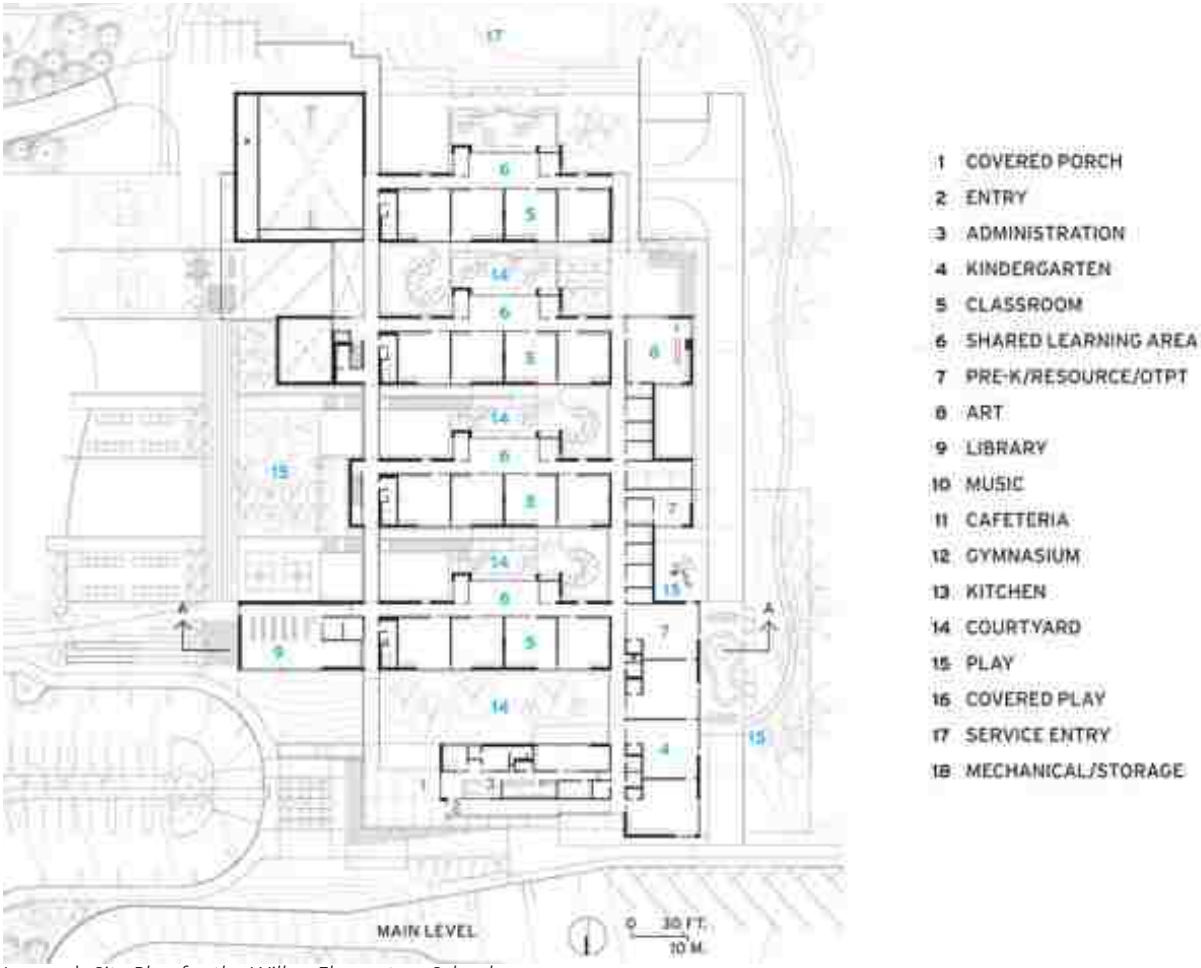


Image d: *Site Plan for the Wilkes Elementary School*

27. *Source : Mahlum , http://www.mahlum.com/projects/Wilkes/index.asp#*

Image e: *Elementary Classroom at Wilkes Elementary School*

All the classrooms face the north south orientation which gives ample opportunity to daylight them. Different strategies have been employed to achieve a uniform distribution of light in the classrooms. The Glazing on the North facade brings in ample diffused light. The skylight is strategically placed which also brings in diffused into the space.

The glass partition on the South end of the classroom not only receives an overspill of Daylight from the corridor but also helps in maintaining the connection with the outdoors. All the strategies together deliver uniform and good quality of daylight into the space.

The organization of various activities within the classrooms were also designed around the availability of Daylight. Therefore it is important to set program organization depending upon daylighting during the early design phase so that it becomes an integral part of the design.

CONCLUSION

The various precedent studies and literature review of schools and classrooms helped in understanding the various factors that make a School space energy efficient and high performance. Through these studies it was observed that among the various parameters the one variable that made a huge impact on the performance of students was daylighting.

"*Daylighting is the Design of Buildings to use light from the sun. Done properly, daylighting in schools can create interesting dynamic interiors supportive of Human Health and activities while reducing energy demand. Done improperly daylighting impedes vision, causes discomfort and demands excessive energy.*"[28]

Adequate amount of natural light and a proper sense of orientation is important so that students can function normally within enclosed learning spaces. Daylighting also helps in balancing the circadian rhythm. The amount of natural light in a classroom will vary depending upon the size and configuration of the windows, skylights, and clerestories. Different design strategies shall allow for screening or blocking daylight when the learning environment requires darkening, usually for projection equipment or other situations in which substantial glare may interfere with activities. Interior blinds may also allow some flexibility for privacy when views or overviews are not desired or required.

28. *Daylighting pattern book / http://www.lrc.rpi.edu/programs/daylighting/pdf/DaylightingPatternBook_Final.pdf*

CHAPTER III

THESIS GOALS AND OBJECTIVES

"Freedom is the most important thing to all human beings and kids love the freedom for self directed learning in both the learning community commons and all school atrium commons."[29]

To carry the research forward following goals were set for the thesis :

- To create a learning environment that stimulates learning, interaction and growth of students and teacher.
- Designing schools that learn: Stuart Brand's notion about making buildings that can adapt and change well.
- Buildings as pedagogy : Building that instruct by what they do
- Learning spaces should be warm and welcoming and should place students at the center of their own educational journey.

Daylighting Goals

- Have ample apertures of daylight and views in the classroom.
- Control glare by minimizing direct sun in all spaces with critical visual tasks
- Avoid under-lit areas by distributing ambient light throughout the space.
- Provide sufficient daylight to perform tasks
- Provide views to outside.

29. *Anne Mitchell, Principal, Roosevelt Elementary.*

METRICS USED

A range of daylighting metrics is used to design the classroom patterns for the research. These metrics helped in studying and defining the daylighting quality of the space. The metrics range from climate based which is an annual metrics to point in time illuminance which is more specific to a particular day and time.

CLIMATE BASED METRICS

DAYLIGHT AUTONOMY : Daylight autonomy may be defined as the percentage of times 50% of the space is above the target illuminace during the occupied hours during a year. (50% > 300 Lux)

USEFUL DAYLIGHT ILLUMINANCE (Autonomy) : Useful daylight Illuminance or UDI may be defined as the percentage of times a space is in the optimum range of 300 lux- 3000 lux during occupied hours during a year.

USEFUL DAYLIGHT ILLUMINANCE (Underlit/Supplementary) : This may be defined as the percentage of times a space is below the target illuminance of 300 lux during occupied hours during a year.

USEFUL DAYLIGHT ILLUMINANCE Overlit/Exceeded) : This may be defined as the percentage of times a space is above the optimum range .i.e >3000 lux during occupied hours during a year.

ANNUAL GLARE ANALYSIS : It is a schedule that highlights the times during a year when the space is under discomfort caused by the direct beam sunlight during the occupied hours during a year.

POINT IN TIME ILLUMINANCE

VISUALIZATION IMAGES : These are visual renders of the interior space for specific day and time of the year.

FALSE COLOR IMAGES : These are visual renders of the interior space for specific day and time of the year showing the dynamic levels of daylight falling on the space in terms of False color.

All the above metrics are carried for the following dates and times under specific sky conditions. The following days and times are selected for running these metrics as the solar angles vary considerable during these durations. For instance the sun is relatively lower in the sky during March and September and higher during June. Also Seattle has 70% cloud cover therefore it becomes important to consider both Overcast skies and clear sky with Sun for the study.

March 21st at noon under Clear Sky with sun , Overcast sky

June 21st at noon under Clear Sky with sun, Overcast sky

September 21st at noon under Clear Sky with sun, Overcast sky.

PARAMETERS

- Research is limited to Elementary School Classrooms where students spend most of their time in one classroom.
- Classroom dimensions are 30’ x 30’ x 12’
- Useful Daylight Illuminance is between 300- 3000 lux
- The study is based in Seattle region.
- Target illuminance is set as 300 lux
- Seattle has 70% annual cloud cover
- Hours of a School day are from 7:00am to 3:00 pm

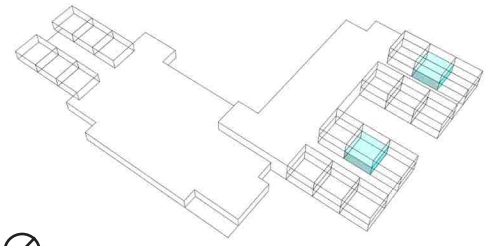
DESIGN VARIABLES

The dimensions of the research were defined by some variables that are identified in the diagram below. These variables affect the patterns of the classroom spaces dramatically. To create a classroom pattern it is important to study these variables separately first and then how each variable interacts with the rest of the variables and evolves to form a functional classroom pattern.

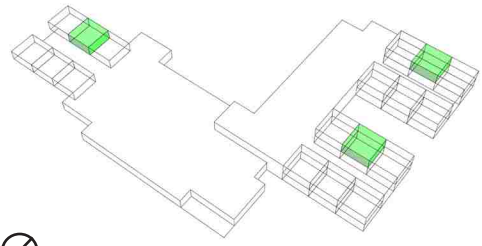
Image f: *Variables of the Study*

01 / TYPOLOGY

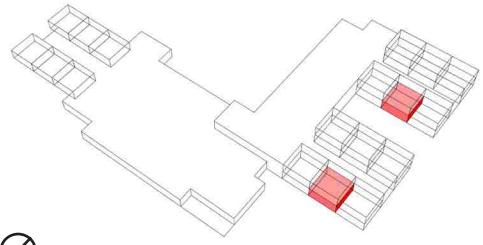
There are various ways of classifying the classroom types but for this research classrooms are classified based on their location. The different locations that a classroom could have are as follows :



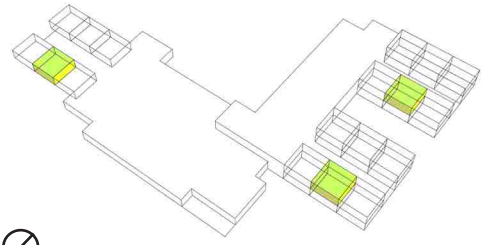
TYPOLOGY 1A- North facing classroom / Lower level



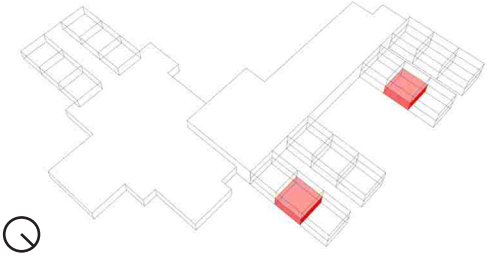
TYPOLOGY 1B- North facing classroom / Upper level



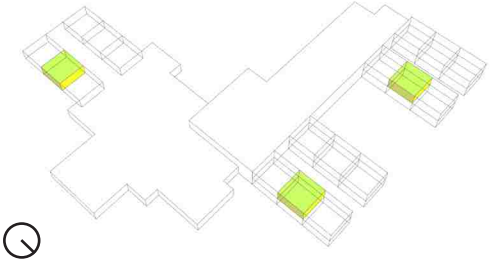
TYPOLOGY 2A- South facing classroom / Lower



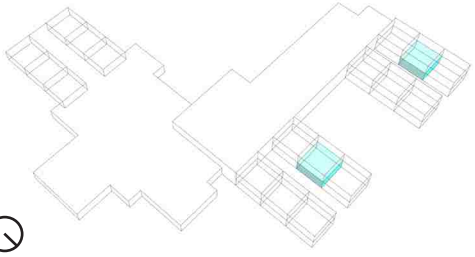
TYPOLOGY 2B- South facing classroom / Upper



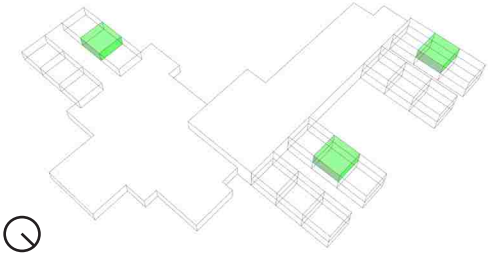
TYPOLOGY 3A- East facing classroom / Lower level



TYPOLOGY 3B- East facing classroom / Upper level



TYPOLOGY 4A- East facing classroom / Lower level



TYPOLOGY 4B- East facing classroom / Upper level

Image g: *Image showing various classroom typologies*

02 / ORIENTATION

Orientation of the classroom plays an important role in designing a classroom space as the Quality of daylight entering the space under clear sky condition is different for all the orientations. North receives diffused light all day long , whereas South receives direct beam sunlight for most of the day. East and west orientation receive direct beam sunlight during morning and evening hours. Thus it becomes critical to design the patterns depending upon strategies that work best for a particular orientation.

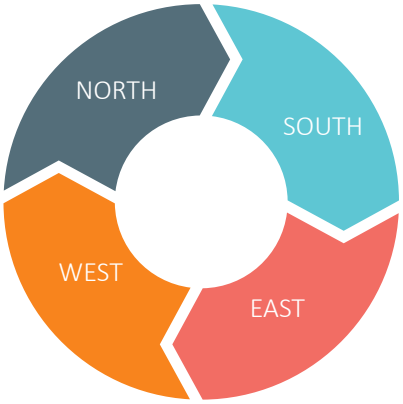


Image h : *Types of Orientation*

03 / SIDE LIGHTING

In spaces without skylights side lighting is the main aperture for letting the daylight into the space. The side lighting not only acts a medium for bringing light into the space but also provides connection to the outside. Strategies for side lighting may vary depending upon the orientation of the classroom and also the location of the classroom. A well lit space is a visual treat. The amount of openings and materials for glass / glazing are extremely important and can tip the balance between a high performance and low performance building. They also impact the building's energy efficiency by affecting cooling loads, heating loads, and lighting loads. The daylight changes in quality throughout the day

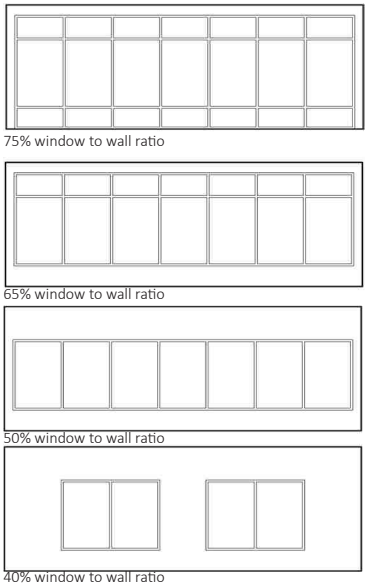


Image i : *Types of Window to Wall Ratios for Classroom patterns*

and with each season. "*Students in classrooms with the largest window area, or the most daylight, were found to be testing 9% to 15% higher than those students in classrooms with the latest window area or daylighting."*[30]

The area of glass relative to wall area, or the window to wall ratio (WWR), is one of the key inter-relationships when designing day-lit buildings. Generally the effective distribution of daylight from perimeter windows is a function of the head height of the windows.

Therefore to obtain a good side lighting strategy different window to wall ratios are designed and observed to find a pattern that brings in the most diffused and reflected daylight with minimum glare possible. The different window to wall ratios considered for this research for various orientations are 75% , 65% , 50% and 40%.

"Direct beam sunlight is an extremely strong source of light, providing up to 10,000 foot-candles of illumination. It is so bright, and so hot, that it can create great visual and thermal discomfort. Daylight, on the other hand, which comes from the blue sky, from clouds, or from diffused or reflected sunlight, is much more gentle and can efficiently provide excellent illumination without the negative impacts of direct sunlight."[31]

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30. Daylighting in Schools *: An investigation into the relationship between daylighting and human performance*

31. Daylight and Fenestration *, Designhttp://www.lightingassociates.org/i/u/2127806/f/tech_sheets/daylighting_and_fenestration_design.pdf*

04 / TOP LIGHTING

Top lighting is another strategy for bringing Daylight into the space. Skylights coupled with side lighting can also eliminate electrical lighting to come extent when designed judiciously. Top-Lighting provides access to the brightest part of the sky on overcast days, the zenith, and has more hours of solar exposure than any other glazing orientation. Therefore substantial amount of daylight is available for long durations and can be delivered into the interior space in a uniform manner. Top lighting does not provide views to the outdoors. The size and placement of the top lighting apertures, their proximity to adjacent reflective surfaces is important while designing the classroom pattern so as to avoid glare potential and the role of ceiling height.

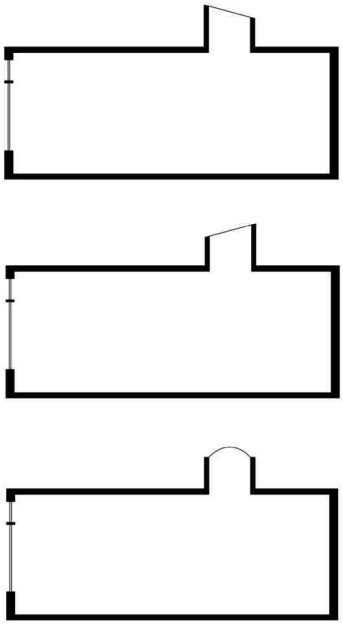


Image j : *Types of Skylights for Classroom patterns*

Skylights play a very vital role in daylighting into a room. They improve the energy efficiency, brighten low-light areas, and provide a much-needed dimension to the rooms. They also cut down on lighting costs. The skylights maybe either fixed or operable.

Skylights mainly have two different functions :

- To bring in light
- Ventilation

The glazing of the skylight may be either clear or diffused.

Top lighting reduces the likelihood of glare and allows for a more even distribution of daylight within the space. It also provides the most uniform illumination throughout a space.

"Top lighting schemes have many other advantages, including freeing up walls for tack space or storage, and increasing security by reducing access to fenestration. 1 ft2 of a diffusing skylight can provide illumination to about 10 times the area of one ft2 of equivalent window glazing. Skylights actually deliver more daylight into a space over the course of a year than comparable vertically oriented glazing."[32]

THUMB RULES FOR DESIGNING SKYLIGHTS

Classroom with many openings : Area of the skylights should not be more than 5% of the floor area. Classroom with few openings : Area of the skylights should not be more than 15% of the floor area.Ideal slope for the skylight is equal to your geographical latitude plus 5 to 15 degrees. For Seattle the ideal slope for a South facing skylight would be 47+5/15 i.e. 52 or 62^0.

05 / SHADING

To provide diffused daylight in the space it is important to control the direct beam sunlight from entering the interior space. Therefore shading plays a vital role in maintaining the quality of the daylight. Different shading strategies are adopted depending upon the orientation of the classroom. For instance North-facing windows usually do not need exterior overhangs or fins as they

32. *Daylight and Fenestration Designhttp://www.lightingassociates.org/i/u/2127806/f/tech_sheets/daylighting_and_fenestration_design.pdf*

receive diffused daylight mostly but they may occasionally require interior blinds or louvers to control glare or for darkening the room. Shading can also be interior and exterior depending on weather the concern is glare or thermal control. Shading can also be either fixed or operable such as overhangs , light shelves or louvers.

06 / GLAZING

The glazing of the windows or skylights may be either transparent or diffused depending upon the quality of the daylight required in the interior space. Transparent glazing provides both daylight and views, whereas the diffused glazing distributes daylight better in the interior space. Diffusion is one of the most important characteristics in selecting a skylight. Good diffusing glazings maximize the spread of light in the space and minimizes glare.

07 / SKY CONDITIONS

Another variable that is important while designing the patterns of the classroom spaces is the sky conditions. The cloud cover also affects the design of the shading devices , top lighting and side lighting considerably. Sky conditions covered in this research are clear sky with sun and overcast skies.

The overcast sky is the one where the sun position cannot be determined. The cloud cover is dense therefore the light is diffused and relatively even over the sky dome. The overcast sky is also 3 times brighter at the zenith than the horizon making the top of the sky dome main source of illumination. Therefore to design classroom patterns overcast skies are used as the minimum design condition.

FLOW CHART

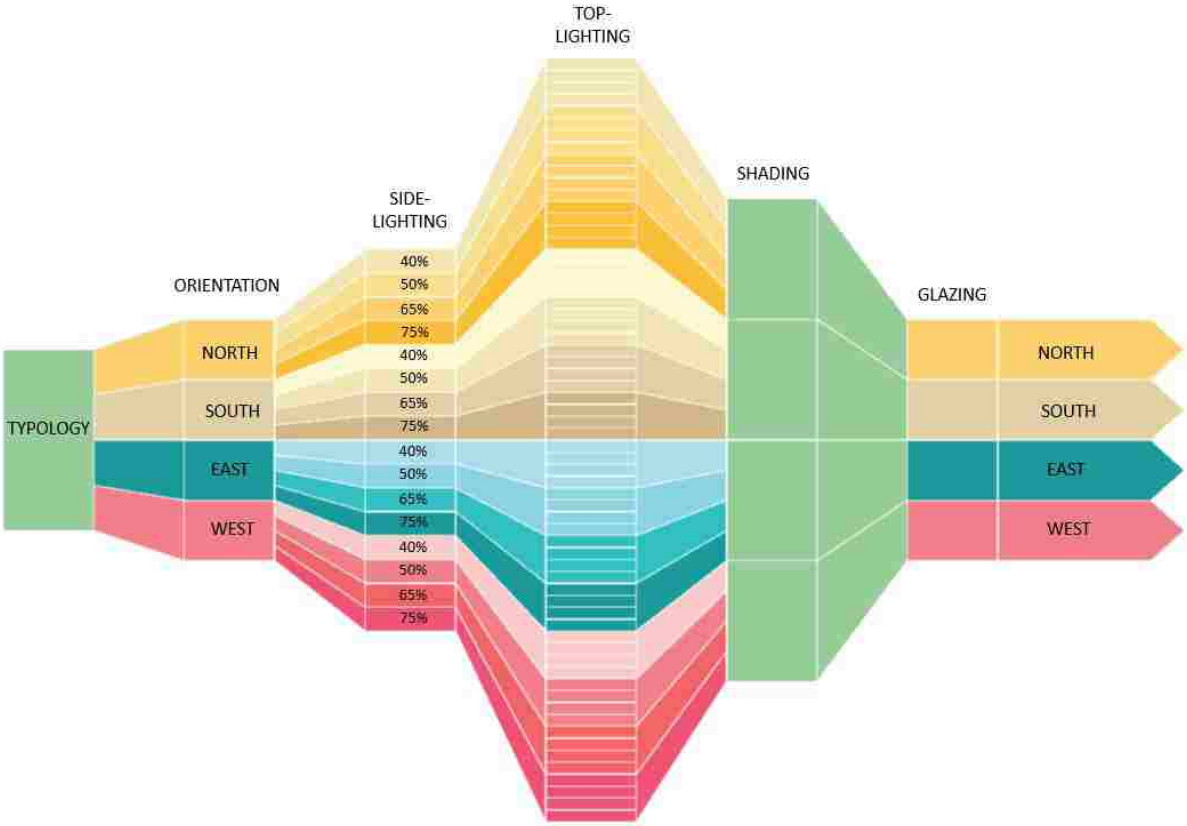


Image k : Methodology of the research and how each variable is considered along the process of designing the patterns.

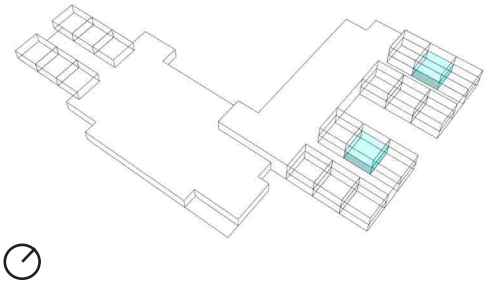
CHAPTER IV

PATTERN DESIGN - TYPOLOGY 1A

Orientation : North

Room size : 30’ x 30’ x 12’

Location : Seattle



SIDE-LIGHTING

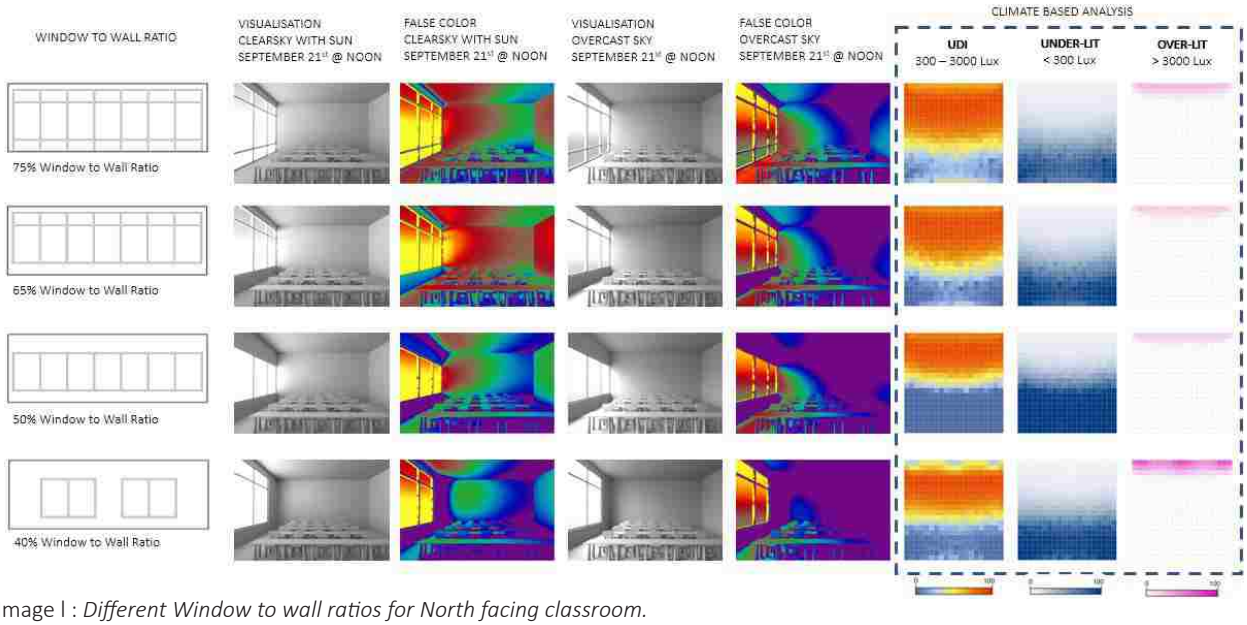


Image l : *Different Window to wall ratios for North facing classroom.*

OBSERVATION

Analyzing different daylighting metrics it is observed that the 75% window to wall ratio has the highest UDI and daylight autonomy making it the favorable ratio for North facing classrooms.

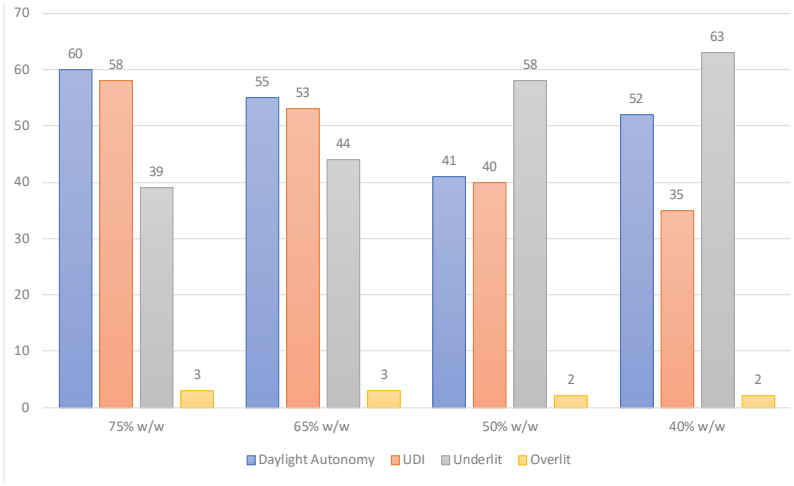


Image m : *Comparative analysis of various illuminances*

SHADING

The daylight entering the classroom through the north facade is mostly diffused. Since there is no direct beam sunlight entering the room no shading is required for this pattern.

GLAZING TYPE

View window : Transparent glass

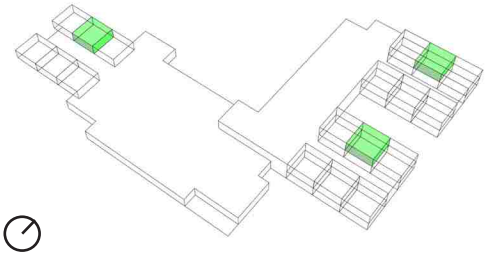
Higher daylight Window: Transparent glass

FINAL PATTERN TYPOLOGY 1A

Image o : *Final Classroom Pattern for Typology 1 .*

PATTERN DESIGN - TYPOLOGY 1B

Orientation : North



The classroom pattern has multiple apertures such as windows and skylights.

TOP-LIGHTING

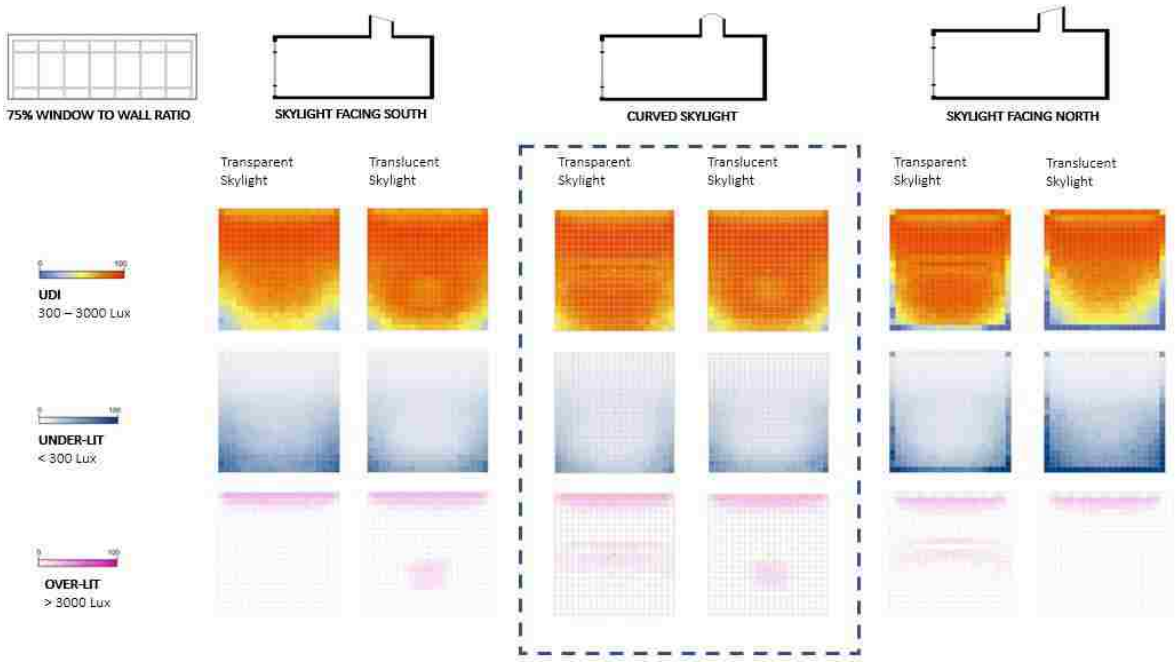


Image p : *Daylight analysis for top-lighting for North facing Classrooms with 75% window to wall ratio*

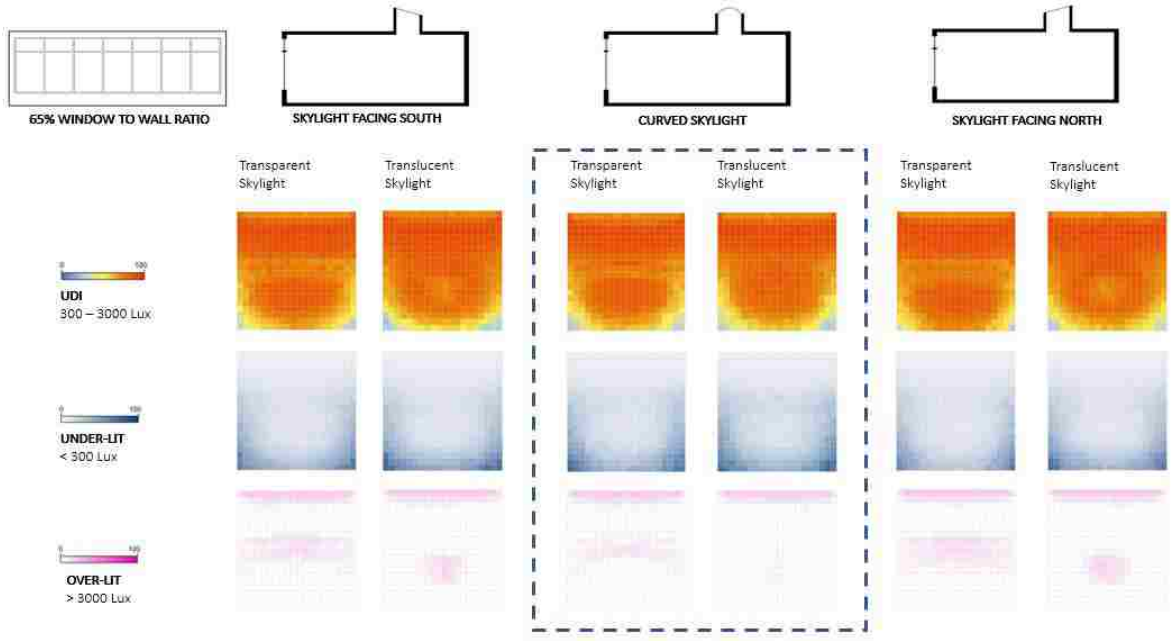


Image q : *Daylight analysis for top-lighting for North facing Classrooms with 65% window to wall ratio*

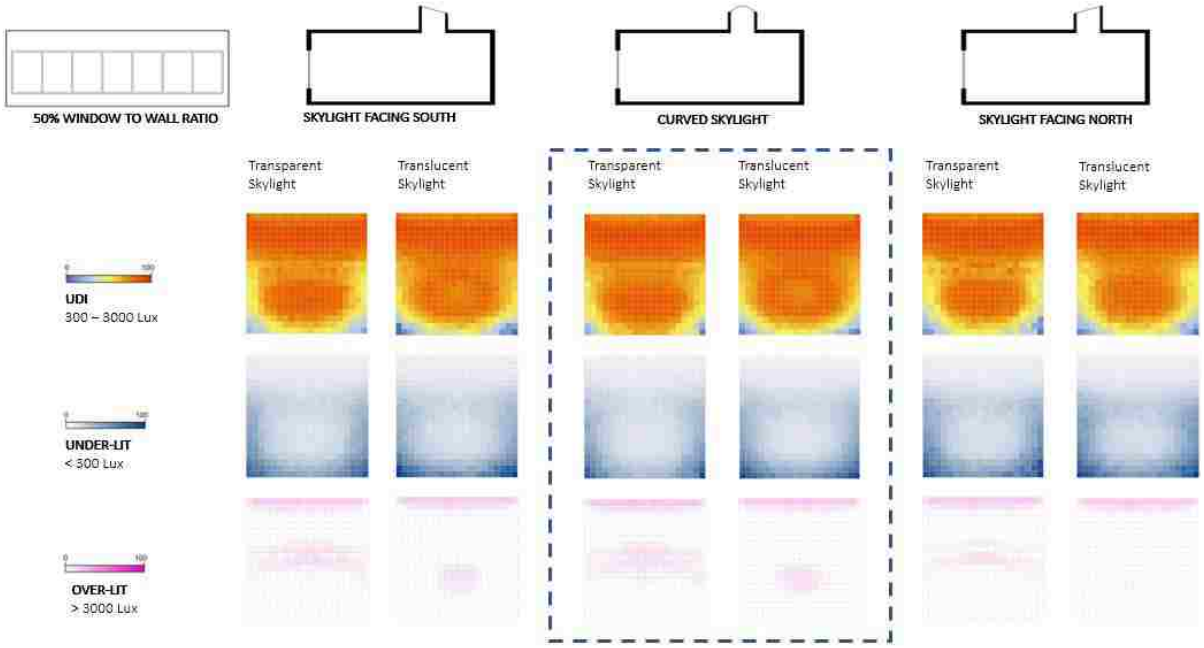


Image r : *Daylight analysis for top-lighting for North facing Classrooms with 50% window to wall ratio*

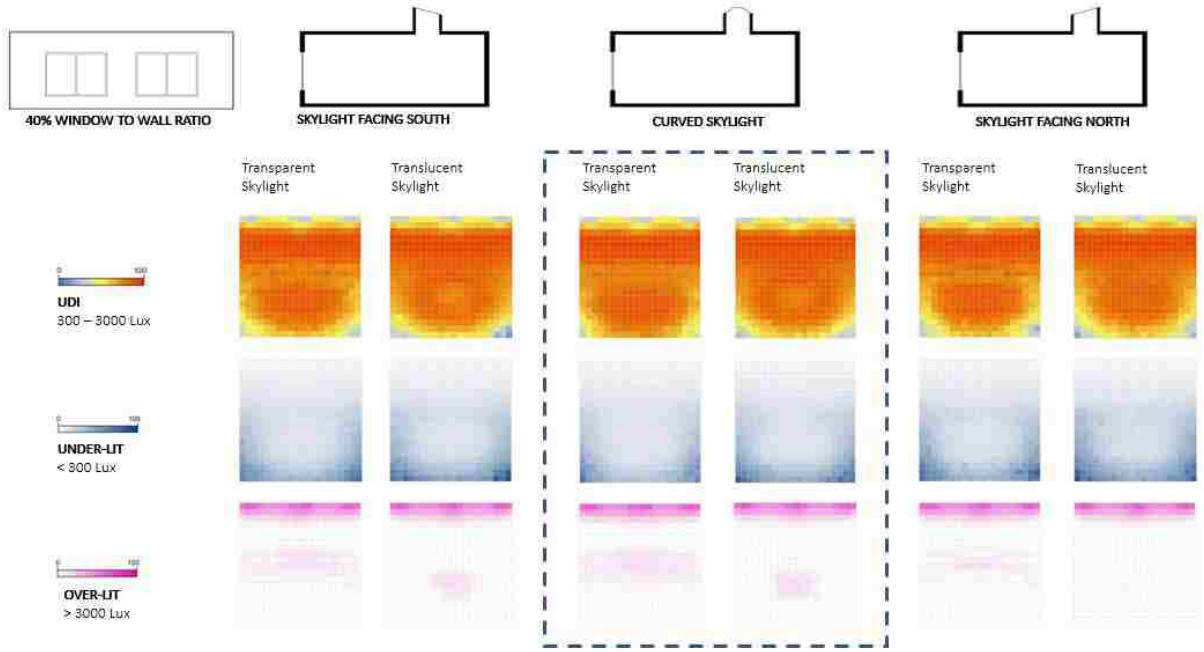


Image s: *Daylight analysis for top-lighting for North facing Classrooms with 40% window to wall ratio*

COMPARATIVE DATA ANALYSIS FOR TOP LIGHTING

	Annual Metrics	Facing South (Translucent)	Facing South (Transparent)	Curved (Translucent)	Curved (Transparent)	Facing North (Translucent)	Facing North (Transparent)
W/W	DA	79	79	78	80	76	78
75%	UDI	75	75	75	77	73	75
	Supplementary	19.7	20	20	18	22	20
	Exceeded	3.2	3.2	3	3.4	2.3	2.8
65%	DA	79	80	80	82	78	79
	UDI	76	77	77	78	76	76
	Supplementary	19	18	18.4	16	21	19
	Exceeded	2.2	2.5	2.4	3.2	1.5	2.6
50%	DA	75	74	73	71	77	75
	UDI	72	72	70	70	74	73
	Supplementary	23	24	26	27	21	23
	Exceeded	3	2	2.5	1.4	3.4	2.1
40%	DA	80.0	79	79	77	82.4	80
	UDI	73	73.2	72	72	74	74
	Supplementary	18	19	19	21	16.0	18
	Exceeded	7	6	6	5	7.4	6

Table : *Comparative data analysis for North facing top lit classrooms*

OBSERVATION

Analyzing different daylighting metrics it is observed that the 75% window to wall ratio along with a curved skylight with translucent glass has the highest UDI and daylight autonomy making it the favorable ratio for North facing classrooms. They have the most uniform light distribution.

SHADING

The daylight entering the classroom through the north facade is mostly diffused. Since there is no direct beam sunlight entering the room no shading is required for this pattern.

GLAZING TYPE

Transparent glass facade and Translucent glass for skylight helps in bringing ample diffused light. The daylight distribution is also uniform throughout the classroom.

PATTERN DESIGN - TYPOLOGY 1B

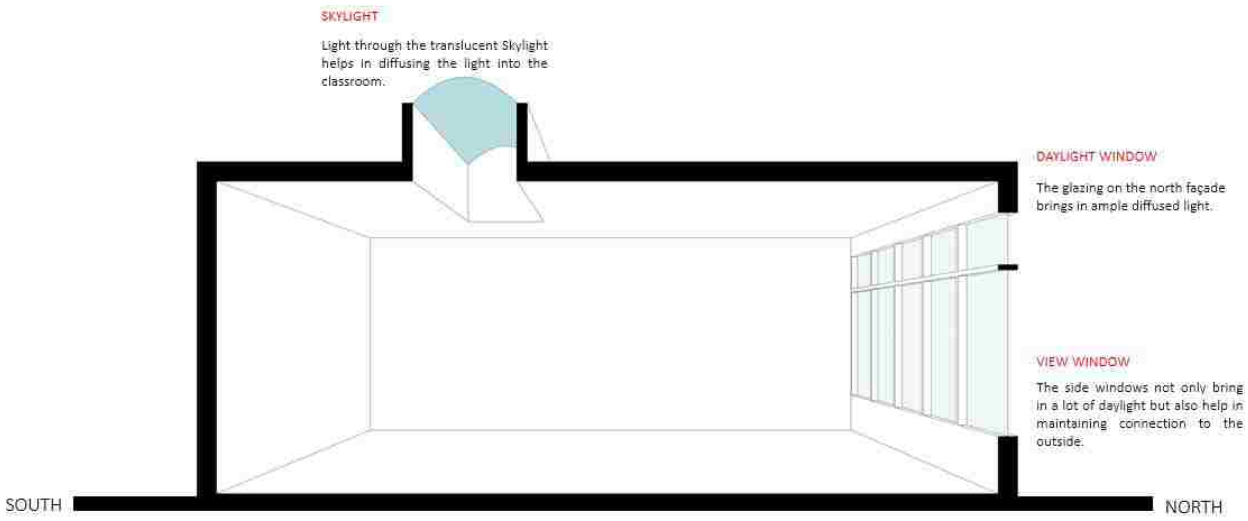
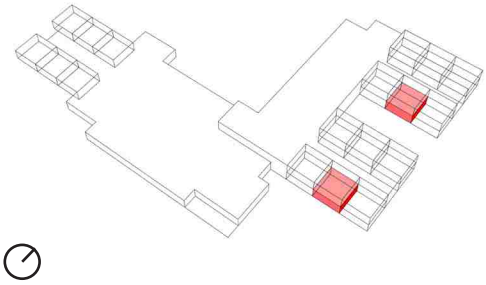


Image t : *Final Classroom Pattern for Typology 2* .

PATTERN DESIGN - TYPOLOGY 2A

Orientation : South

Room size : 30’ x 30’ x 12’



SIDE-LIGHTING

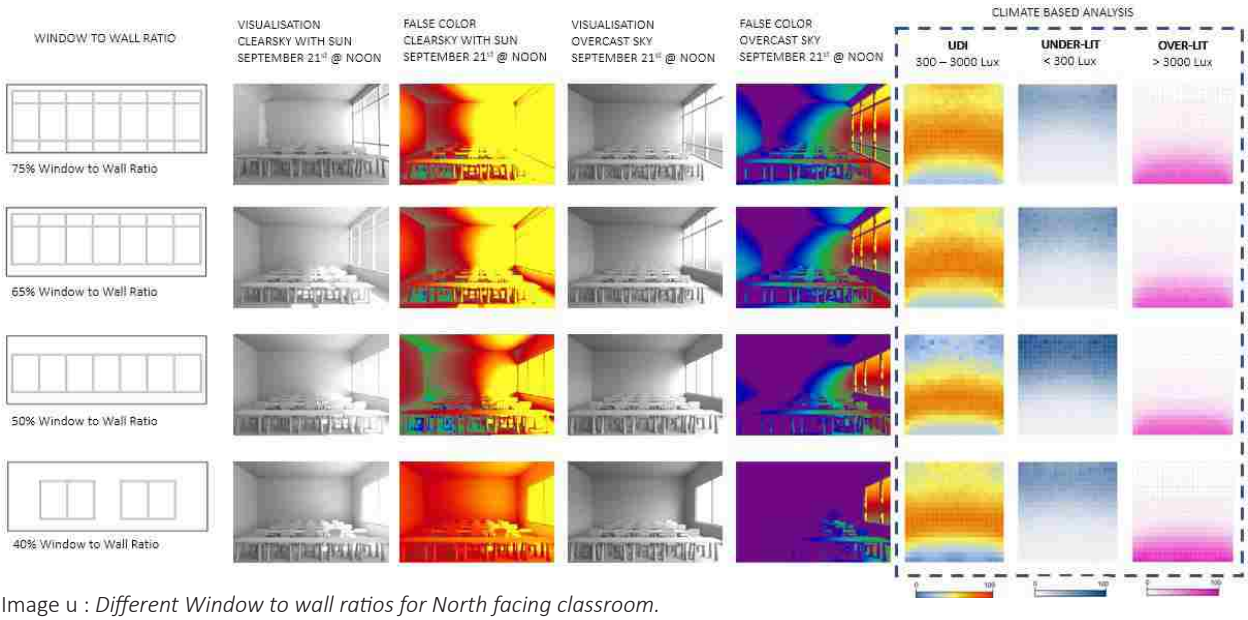


Image u : *Different Window to wall ratios for North facing classroom.*

OBSERVATION

Analyzing different daylighting metrics it is observed that the 65% window to wall ratio has good balance of UDI and over areas making it favorable for South orientation.

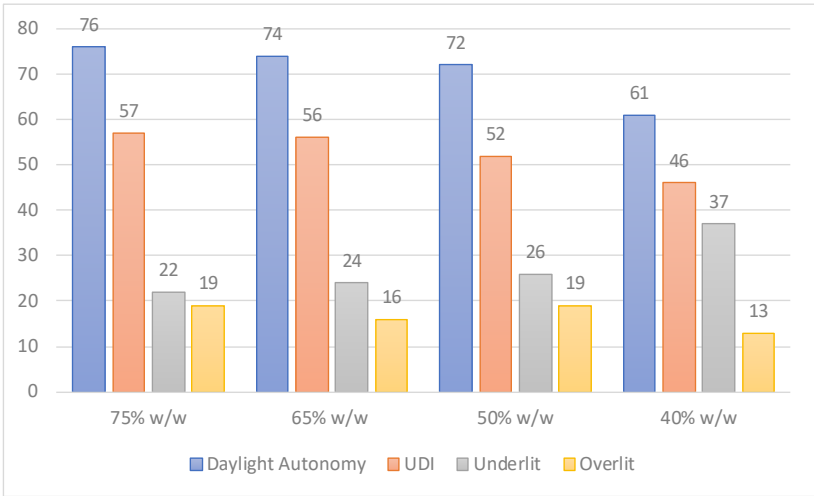


Image v : Comparative analysis of various illuminances

SHADING

The south facade receives a lot of direct beam sunlight. This if not controlled shall cause discomfort to the students. Therefore it is important to control the Direct beam sunlight by designing overhand=gs over the view windows. Another design strategy to diffuse light in to the rear of the classroom is to introduce light shelves. These light shelves bounce the direct beam sunlight falling on it to the ceiling thus illuminating the ceiling.

GLAZING TYPE

View Window : Transparent glass

Daylight Window : Transparent glass

FINAL PATTERN TYPOLOGY 2A

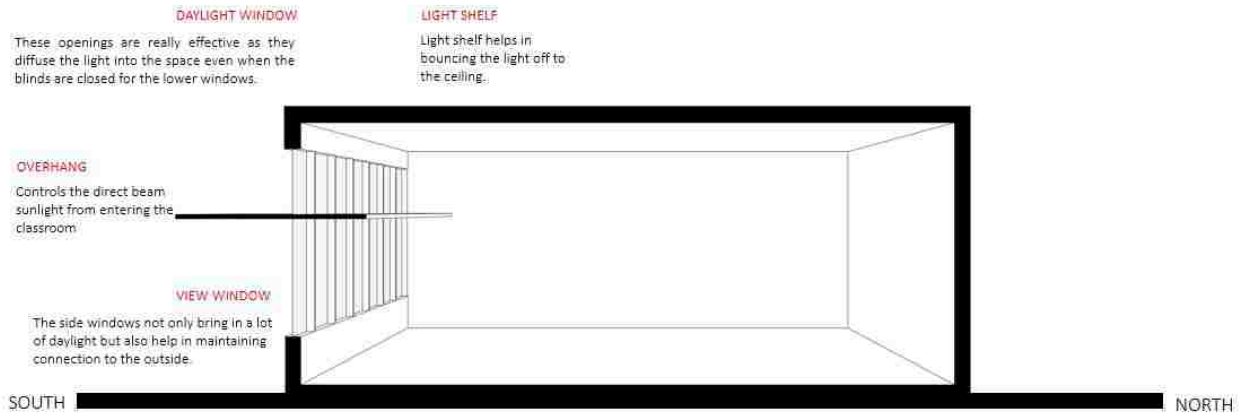
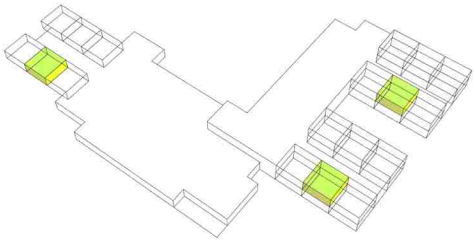


Image w : *Final Classroom Pattern for Typology 3 .*

PATTERN DESIGN - TYPOLOGY 2B



Orientation : South

The classroom pattern has multiple apertures such as windows and skylights.

TOP-LIGHTING

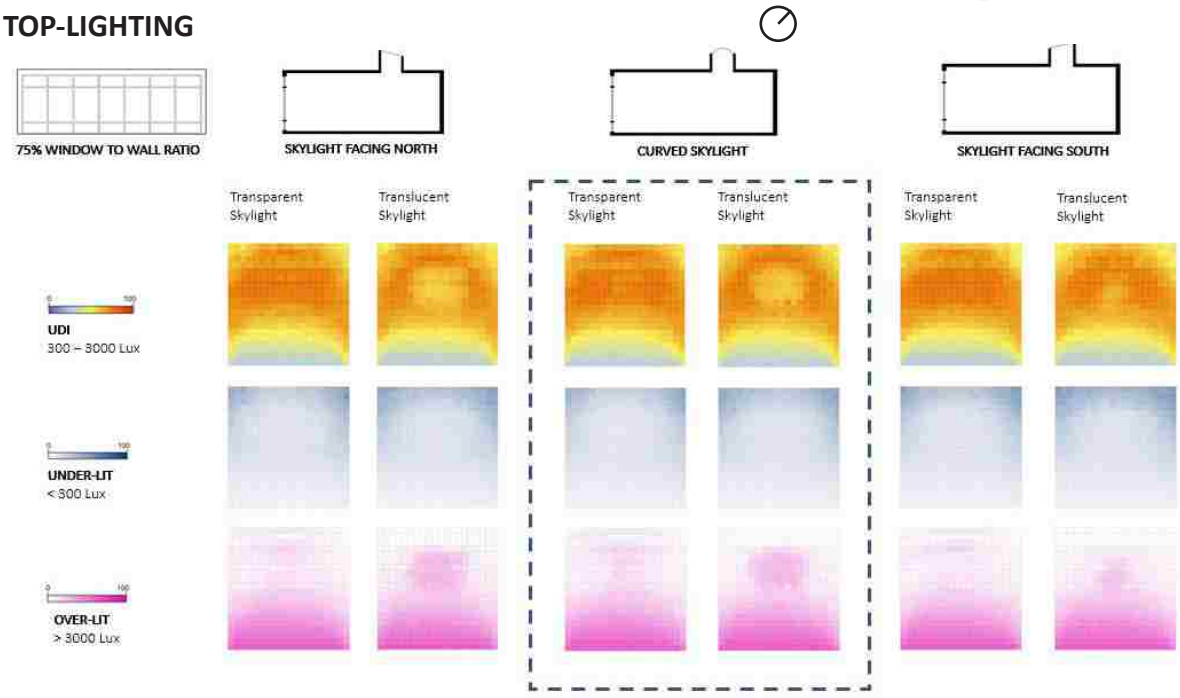


Image x : *Daylight analysis for top-lighting for South facing Classrooms with 75% window to wall ratio*

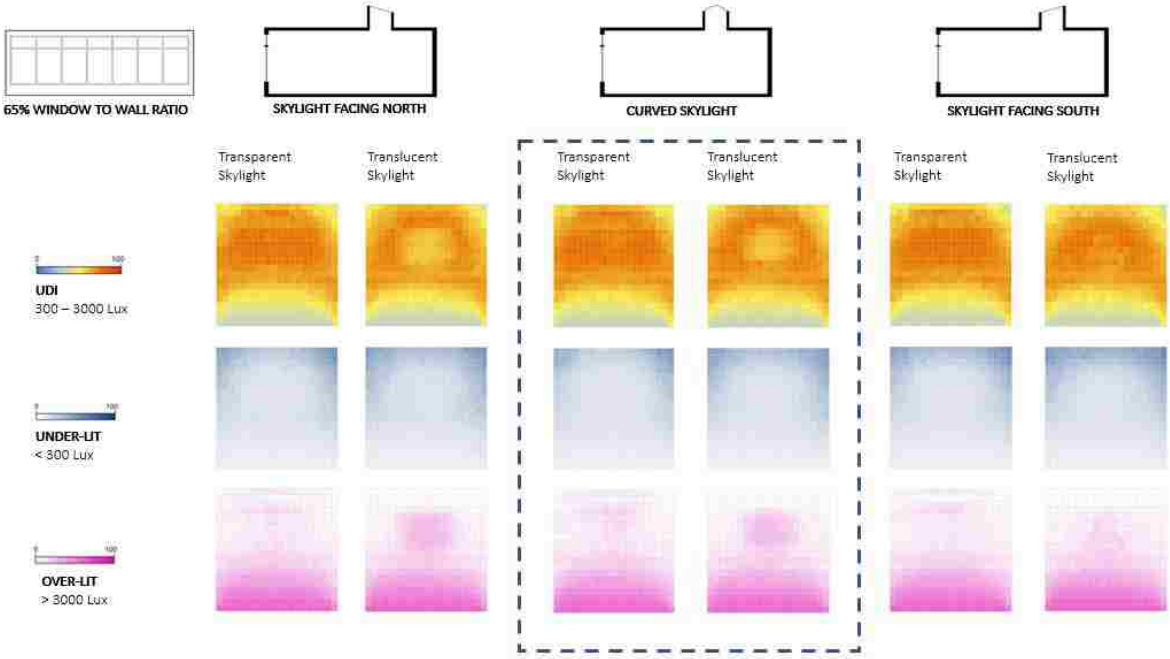


Image y : *Daylight analysis for top-lighting for South facing Classrooms with 65% window to wall ratio*

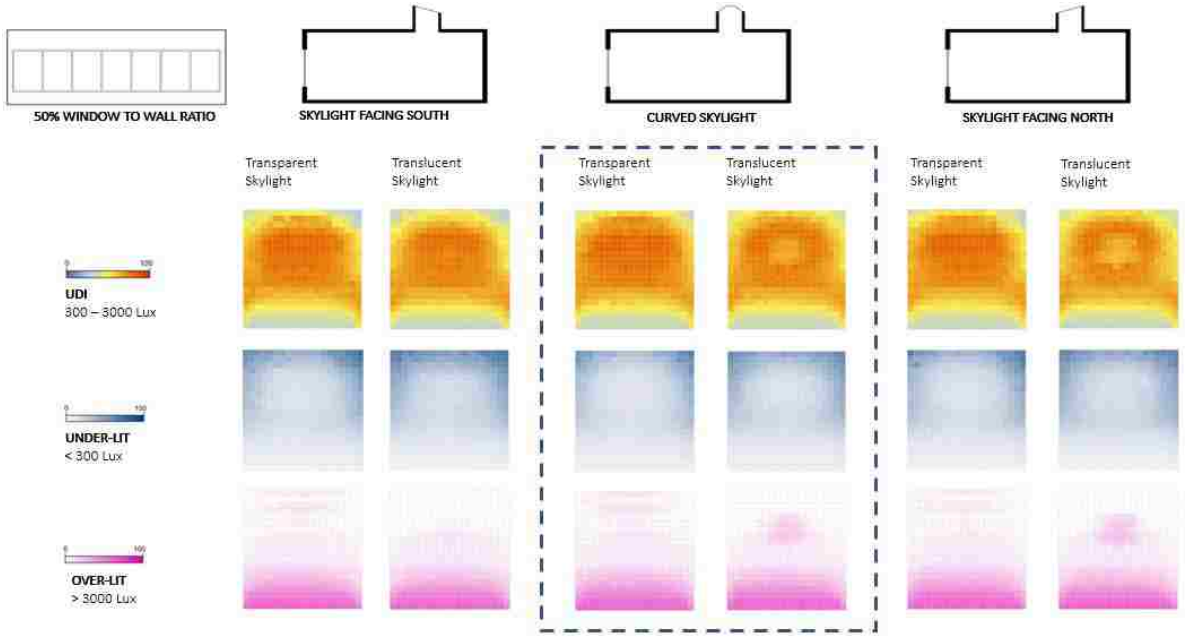


Image z: *Daylight analysis for top-lighting for South facing Classrooms with 50% window to wall ratio*

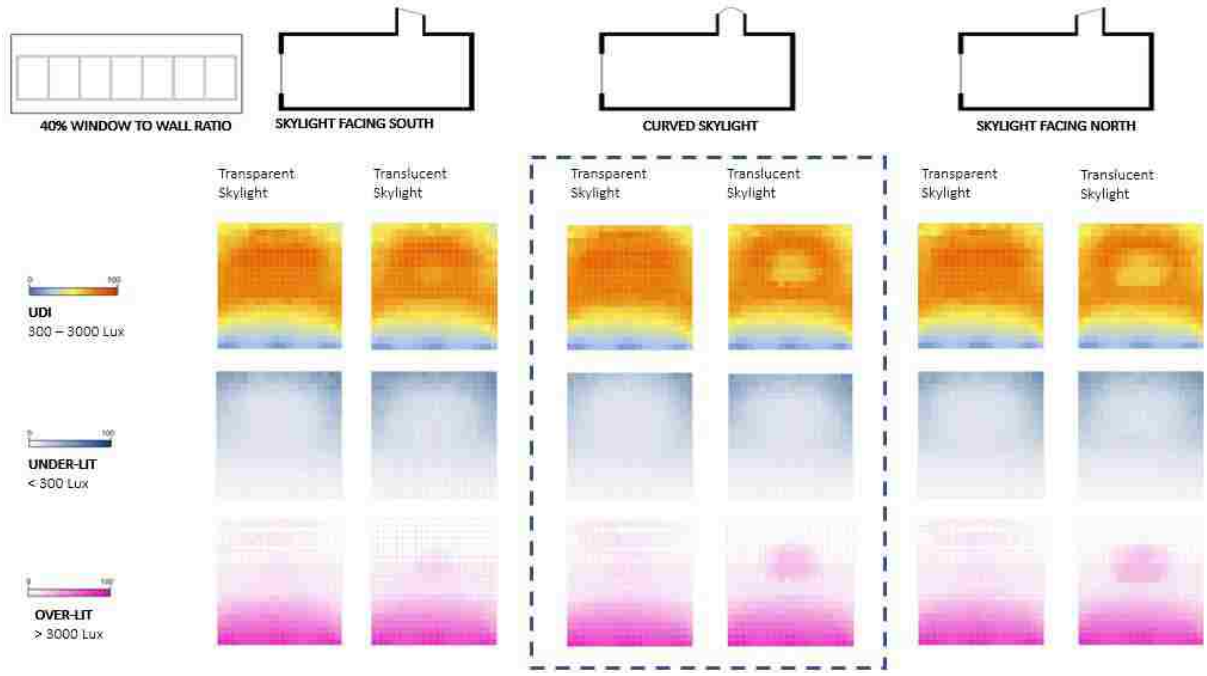


Image aa : *Daylight analysis for top-lighting for South facing Classrooms with 40% window to wall ratio*

COMPARATIVE DATA ANALYSIS FOR TOP LIGHTING

	Annual Metrics	Facing South (Translucent)	Facing South (Transparent)	Curved (Translucent)	Curved (Transparent)	Facing North (Translucent)	Facing North (Transparent)
W/W	DA	82	84	83	84	81	83
75%	UDI	58	61	59	61	59	61
	Supplementary	16	14	15	14	17	14
	Exceeded	23	22	23	22	21	21
65%	DA	81	82	82	84	80	82
	UDI	60	62	60	62	60	62
	Supplementary	17	16	16	15	18	16
	Exceeded	21	20	20	20	19	19
50%	DA	76	78	78	80	75	78
	UDI	60	61	61	63	60	61
	Supplementary	22	20	20	18	23	20
	Exceeded	16	16	16	16	15	15
40%	DA	84	82	82	81	82	81
	UDI	61	59	60	58	60	58
	Supplementary	15	16	16	17	16	18
	Exceeded	22	22	21	22	21	21

OBSERVATION

Analyzing different daylighting metrics it is observed that the 65% window to wall ratio along with a curved skylight with translucent glass has the highest UDI and daylight autonomy making it the favorable ratio for north facing classrooms. They have the most uniform light distribution.

SHADING

The south facade receives a lot of direct beam sunlight. This if not controlled shall cause discomfort to the students. Therefore it is important to control the direct beam sunlight by designing overhangs over the view windows. Another design strategy to diffuse light in to the rear of the classroom is to introduce light shelves. These light shelves bounce the direct beam sunlight falling on it to the ceiling thus illuminating the ceiling.

GLAZING TYPE

View Window : Transparent glass facade

Daylight Window : Translucent glass

Skylight : Translucent glass

FINAL PATTERN TYPOLOGY 2B

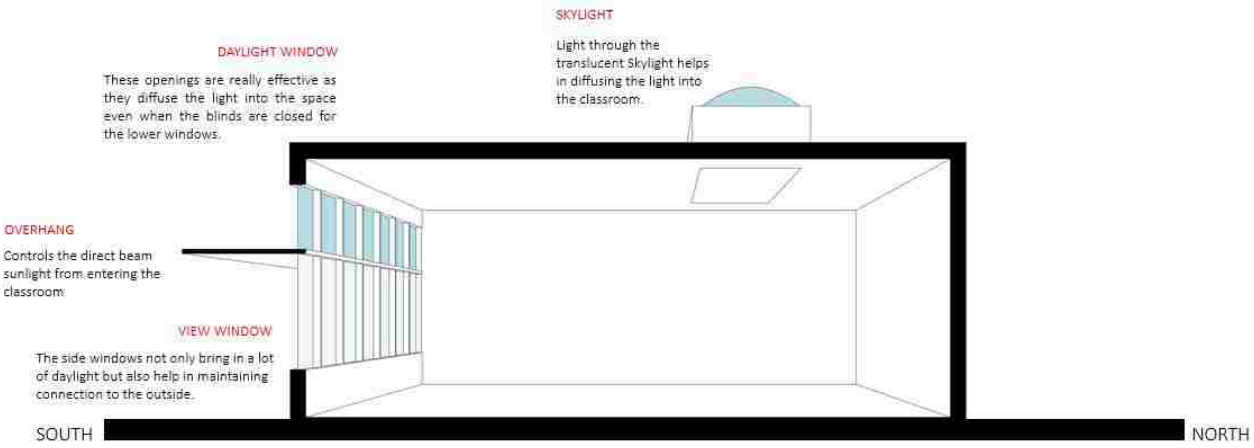
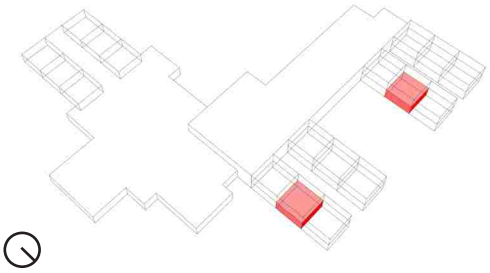


Image bb : *Final Classroom Pattern for Typology 4 .*

PATTERN DESIGN - TYPOLOGY 3A

Orientation : East

Room size : 30’ x 30’ x 12’



SIDE-LIGHTING

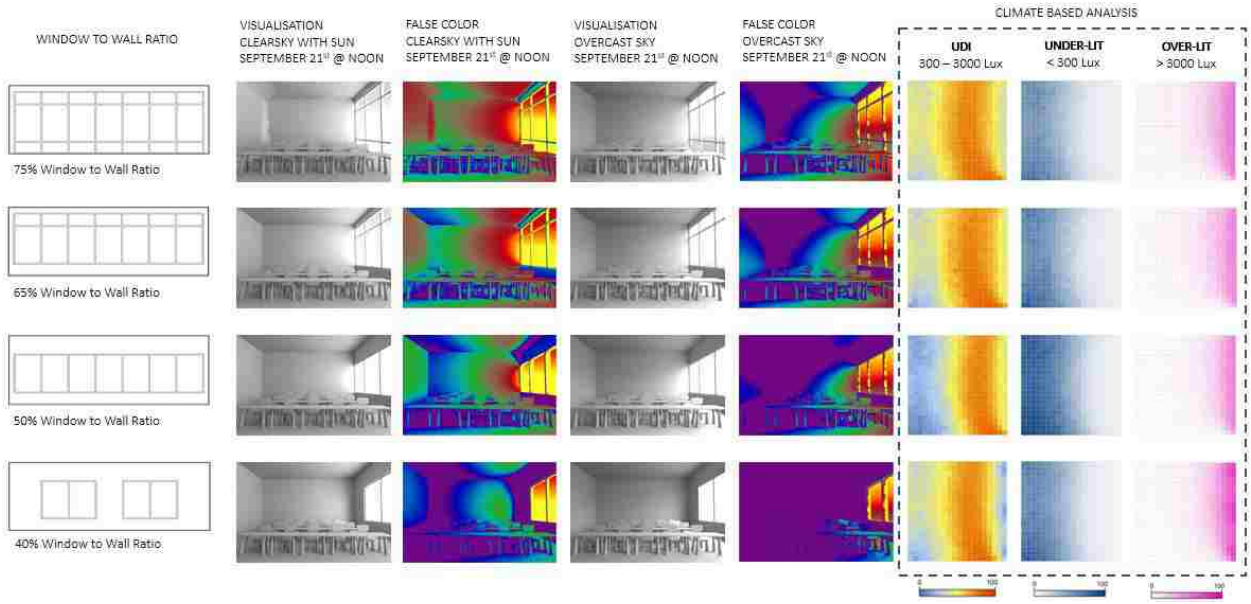


Image cc : *Different Window to wall ratios for East facing classroom.*

OBSERVATION

Analyzing different daylighting metrics it is observed that the 75% window to wall ratio has good balance of UDI and over-lit areas making it favorable for west orientation.

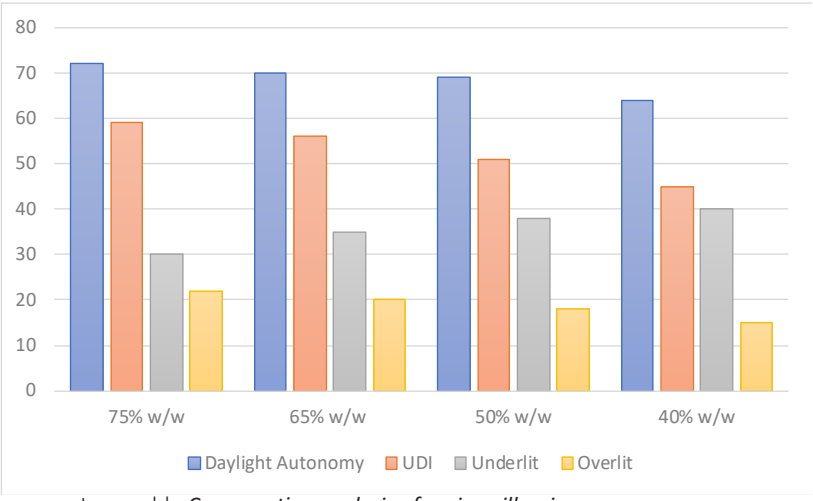


Image dd : *Comparative analysis of various illuminances*

SHADING

The east facade gets a lot of direct beam sunlight into the classroom. Therefore it is important to control the glare which may cause discomfort. Since the sun is much lower on the east therefore vertical louvers control the direct beam sunlight effectively.

GLAZING TYPE

Transparent glass works effectively along with vertical louvers for this pattern.

FINAL PATTERN TYPOLOGY 3A

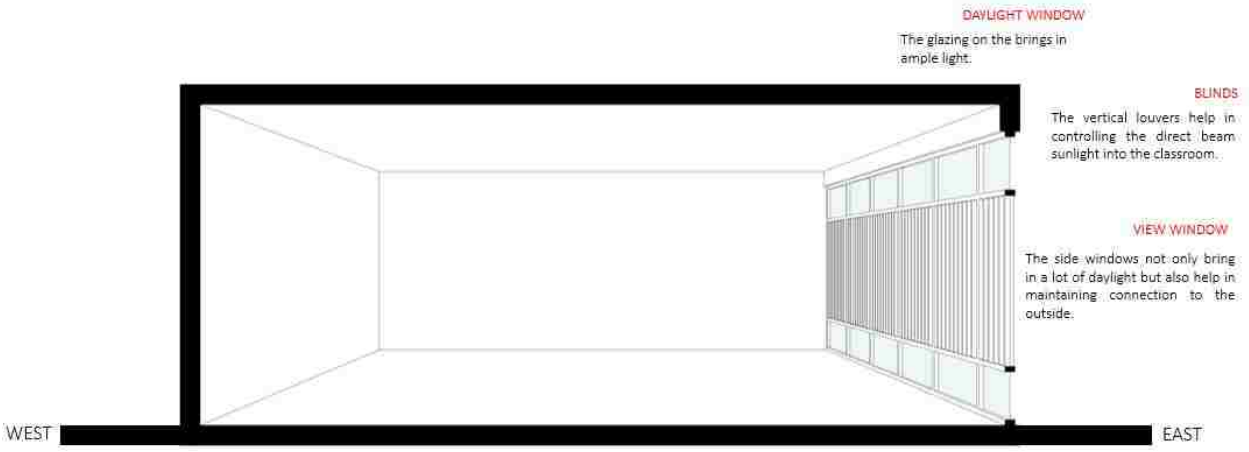
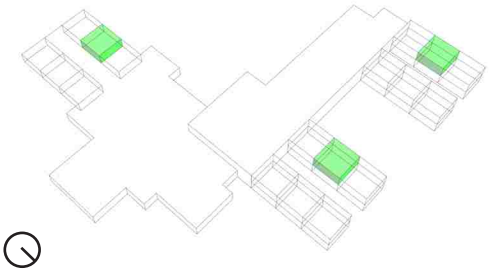


Image ee : *Final Classroom Pattern for Typology 5*

PATTERN DESIGN - TYPOLOGY 3B

Orientation : East

The classroom pattern has multiple apertures such as windows and skylights.



TOP-LIGHTING

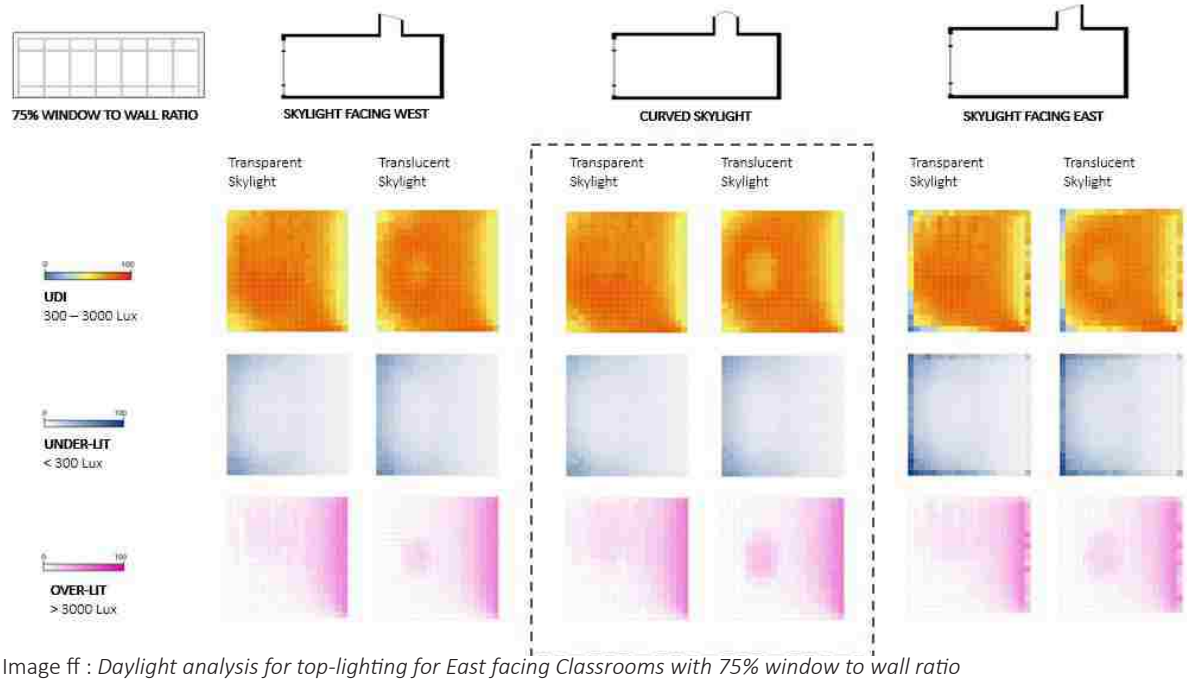


Image ff : *Daylight analysis for top-lighting for East facing Classrooms with 75% window to wall ratio*

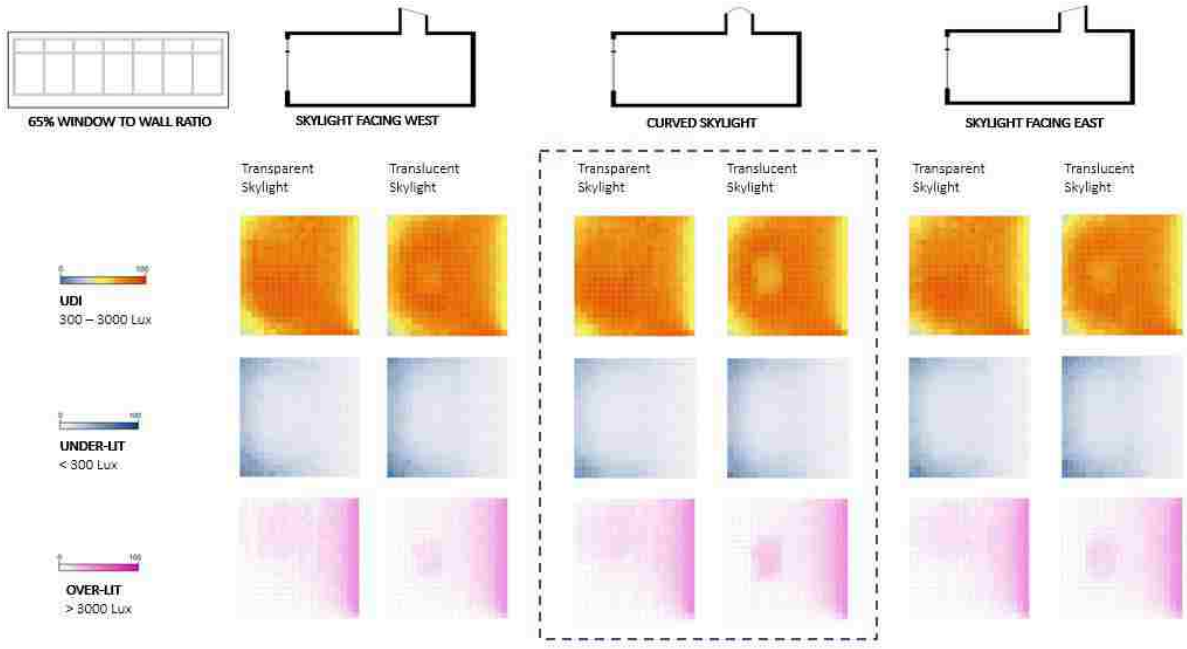


Image gg : *Daylight analysis for top-lighting for East facing Classrooms with 65% window to wall ratio*

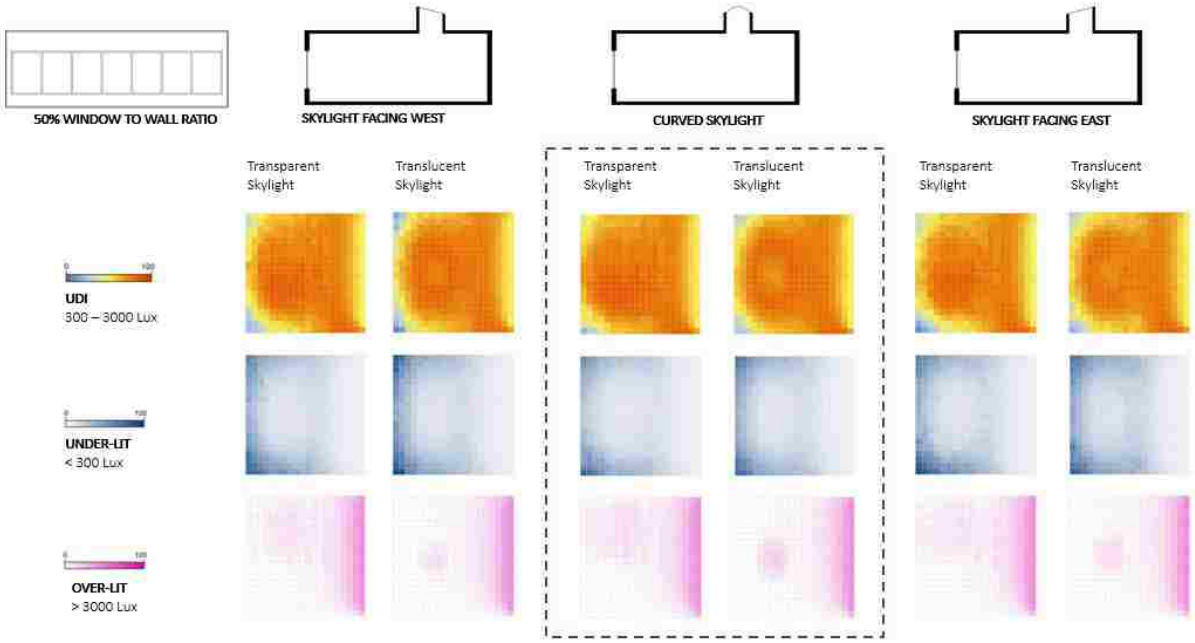


Image hh : *Daylight analysis for top-lighting for East facing Classrooms with 50% window to wall ratio*

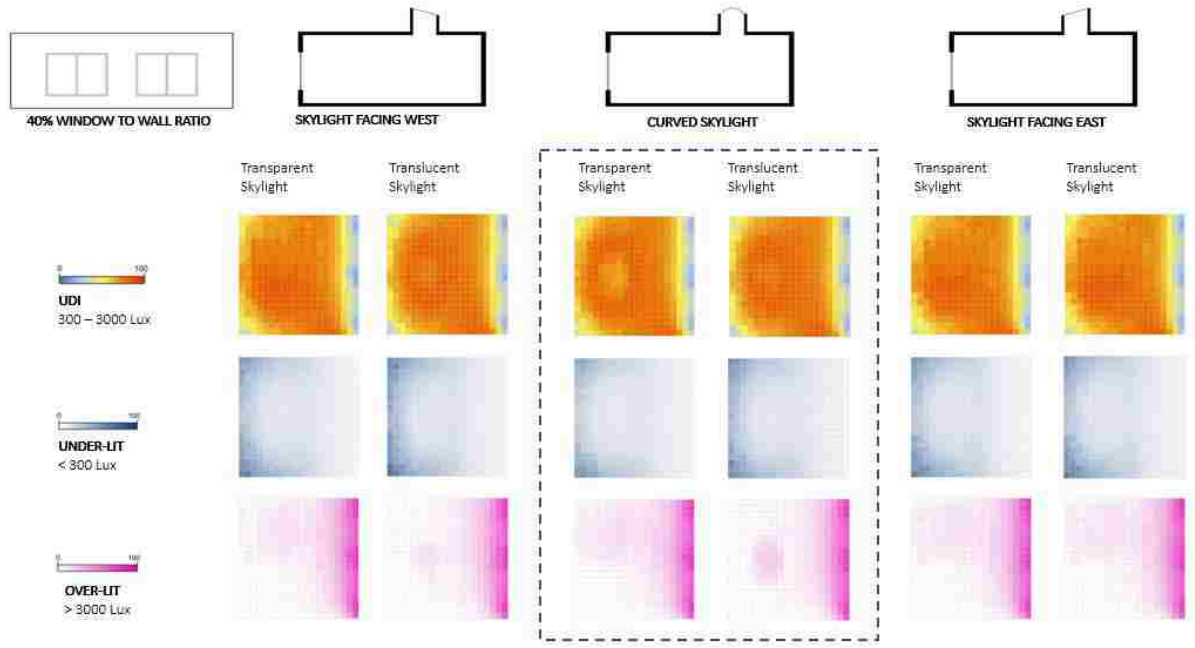


Image ii : *Daylight analysis for top-lighting for East facing Classrooms with 40% window to wall ratio*

COMPARATIVE DATA ANALYSIS FOR TOP LIGHTING

W/W	Annual Metrics	Facing West (Translucent)	Facing West (Transparent)	Curved (Translucent)	Curved (Trans-parent)	Facing East (Translucent)	Facing East (Transparent)
75%	DA	79	80	84	85	83	84
	UDI	67	68	70	71	70	70
	Supplementary	19	18	14	13	15	14
	Exceeded	12	12	13	14	12	13
65%	DA	81	83	83	84	81	83
	UDI	70	70	71	72	71	71
	Supplementary	17	16	15	14	17	15
	Exceeded	10	11	10	11	11	11
50%	DA	76	77	79	81	77	78
	UDI	67	67	69	70	68	68
	Supplementary	22	21	19	17	21	20
	Exceeded	8.7	9.8	9	10	8	9.7
40%	DA	84	83	82	81	83	81
	UDI	69	68	67	66	67	67
	Supplementary	14	15	16	17	15	17
	Exceeded	15	14	14	13	14	13

OBSERVATION

Analyzing different daylighting metrics it is observed that the 65% window to wall ratio along with a curved skylight with translucent glass has the highest UDI and daylight autonomy making it the favorable ratio for East facing classrooms. They have the most uniform light distribution.

SHADING

The east facade gets a lot of direct beam sunlight into the classroom. Therefore it is important to control the glare which may cause discomfort. Since the sun is much lower on the east therefore vertical shades control the direct beam sunlight effectively.

GLAZING TYPE

View Window : Transparent glass facade

Daylight Window : Transparent glass

Skylight : Translucent glass

FINAL PATTERN TYPOLOGY 3B

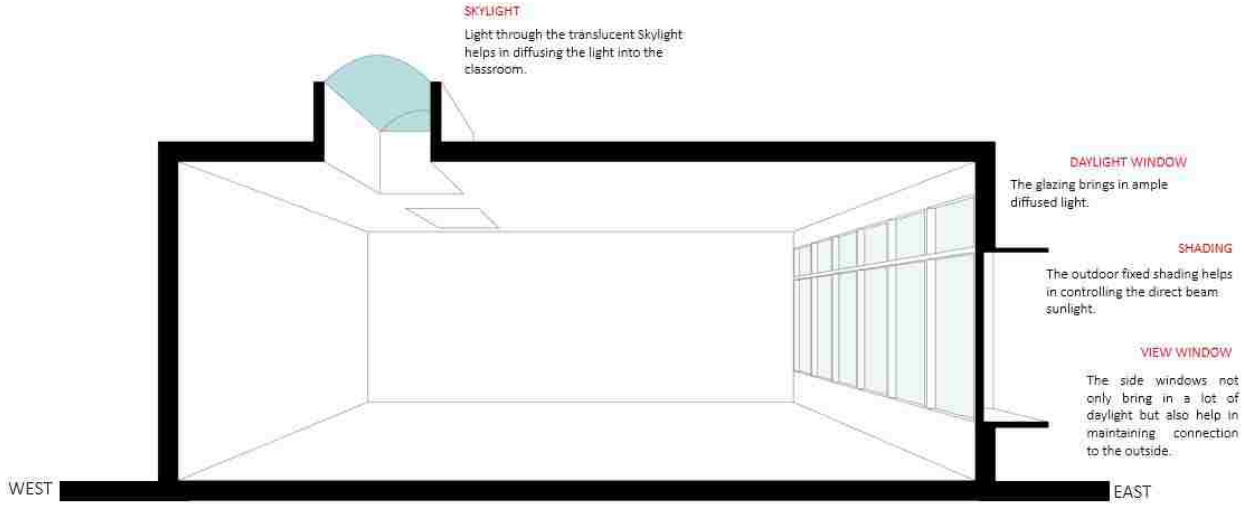
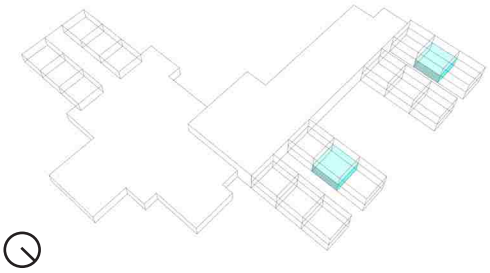


Image jj : *Final Classroom Pattern for Typology 6*

PATTERN DESIGN - TYPOLOGY 4A

Orientation : West

Room size : 30’ x 30’ x 12’



SIDE-LIGHTING

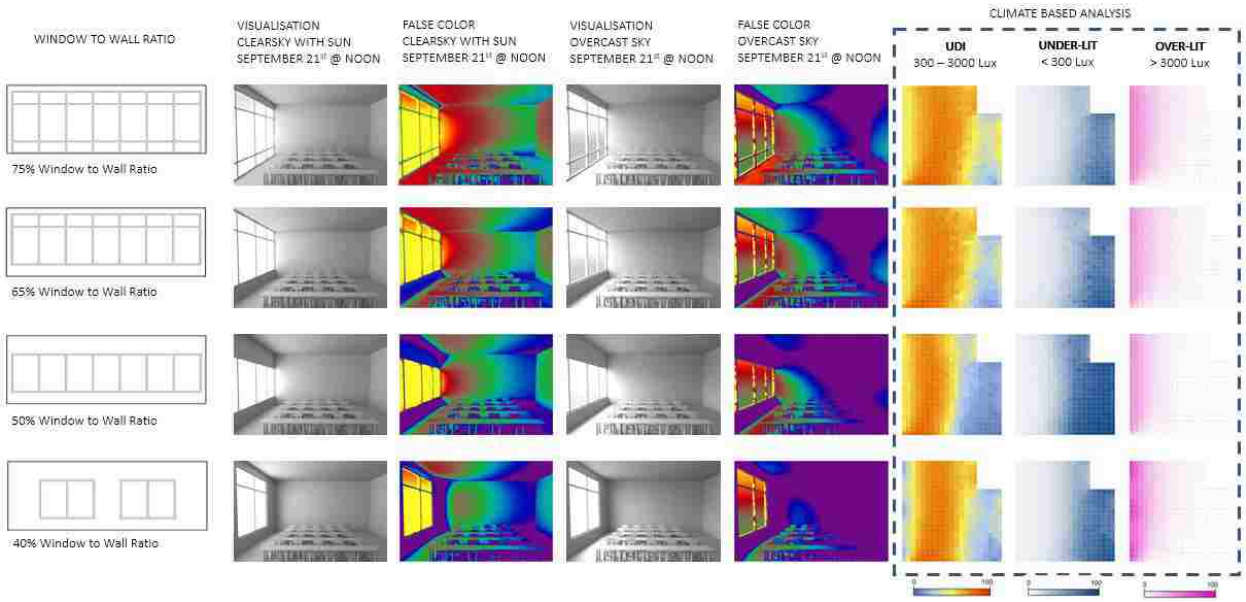


Image kk : *Different Window to wall ratios for West facing classroom.*

OBSERVATION

Analyzing different daylighting metrics it is observed that the 75% window to wall ratio has good balance of UDI and over-lit areas making it favorable for west orientation.

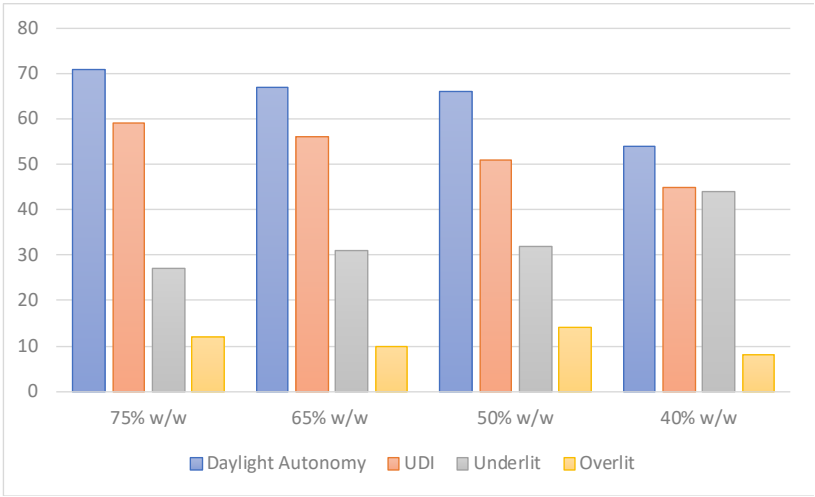


Image ll : *Comparative analysis of various illuminances*

SHADING

The daylight entering the classroom through the west facade is mostly diffused. Since there is no direct beam sunlight entering the room no shading is required for this pattern.

GLAZING TYPE

View Window : Transparent glass facade

Daylight Window : Transparent glass

FINAL PATTERN TYPOLOGY 4A

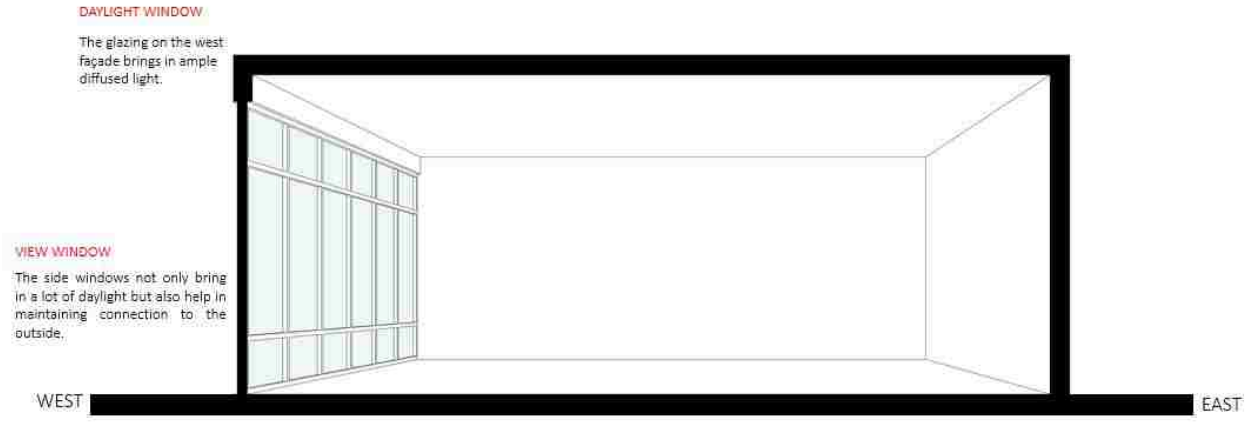
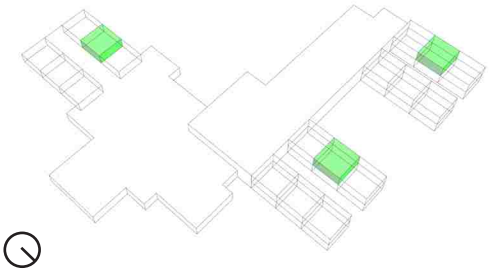


Image mm : *Final Classroom Pattern for Typology 7* .

PATTERN DESIGN - TYPOLOGY 4B

Orientation : West

The classroom pattern has multiple apertures such as windows and skylights.



TOP-LIGHTING

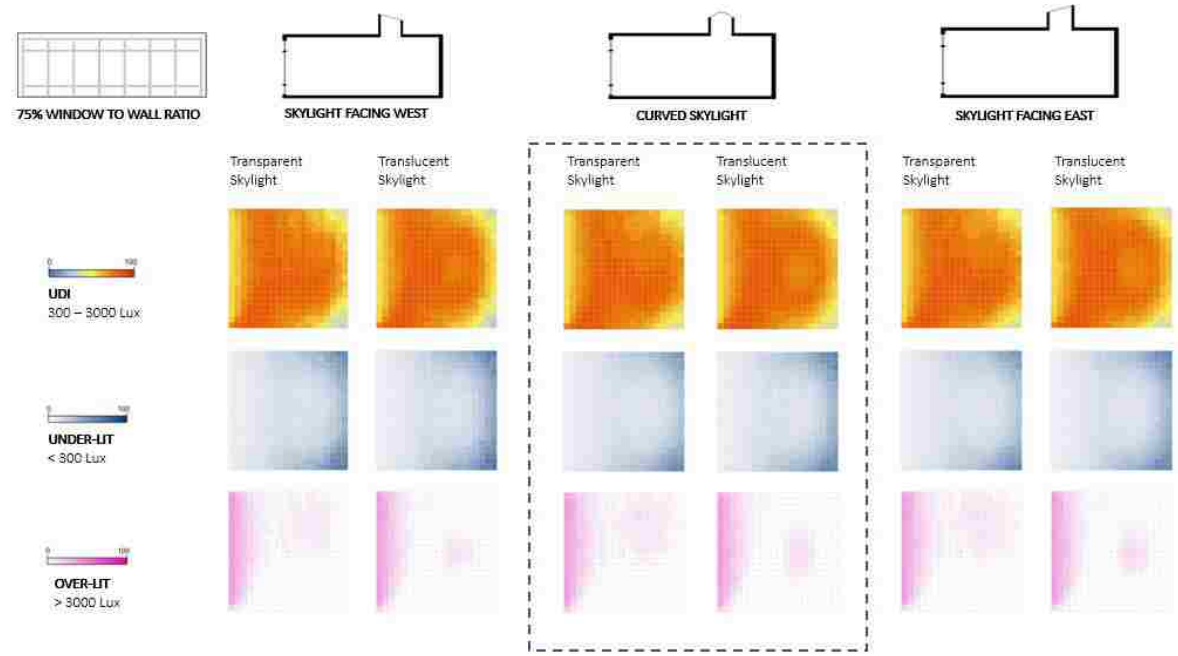


Image nn : *Daylight analysis for top-lighting for West facing Classrooms with 75% window to wall ratio*

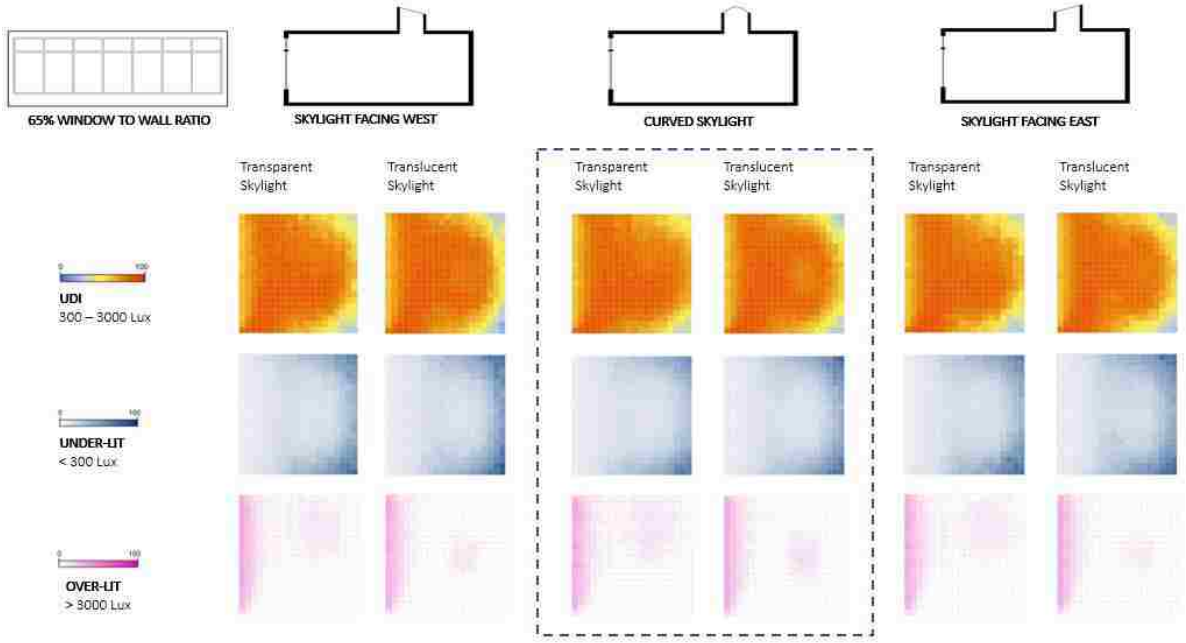


Image oo : *Daylight analysis for top-lighting for West facing Classrooms with 65% window to wall ratio*

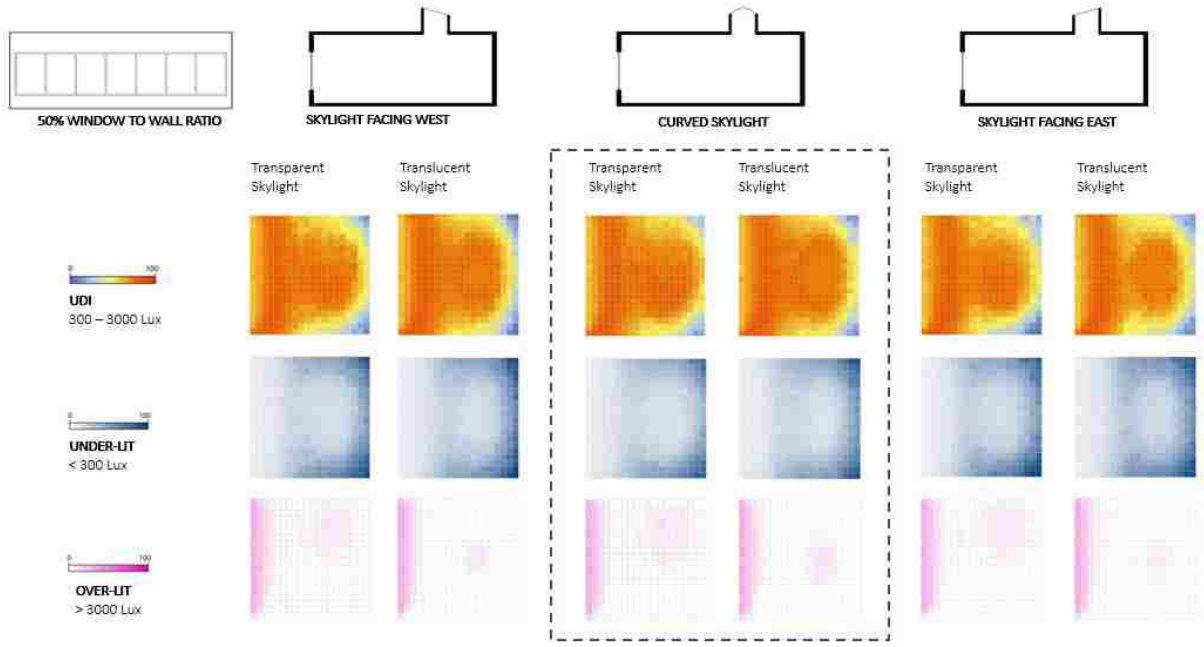


Image pp : *Daylight analysis for top-lighting for West facing Classrooms with 50% window to wall ratio*

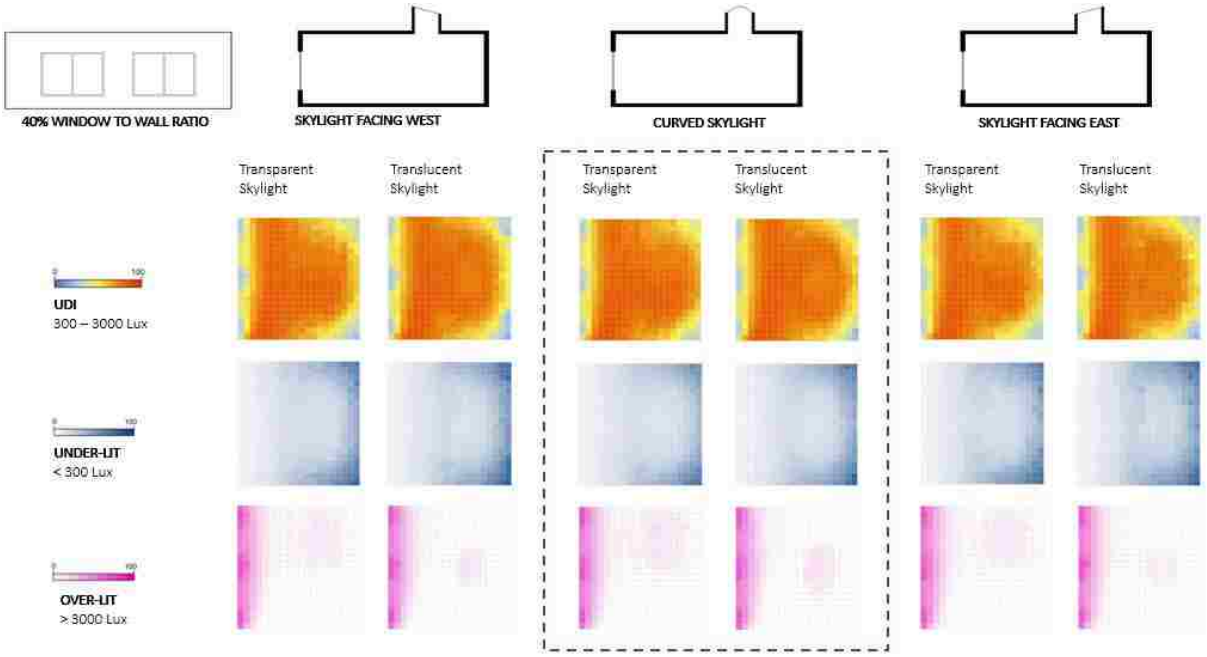


Image qq : *Daylight analysis for top-lighting for West facing Classrooms with 40% window to wall ratio*

COMPARATIVE DATA ANALYSIS FOR TOP LIGHTING

	Annual Metrics	Facing West (Translucent)	Facing West (Transparent)	Curved (Translucent)	Curved (Trans-parent)	Facing East (Translucent)	Facing East (Transparent)
W/W	DA	83	84	84	86	83	84
75%	UDI	69	70	70	71	70	70
	Supplementary	16	14	14	12	15	14
	Exceeded	13	13	13	14	12	13
65%	DA	80	78	77	75	78	76
	UDI	74	73	72	71	72	71
	Supplementary	19	20	21	23	20	22
	Exceeded	5.6	4.6	5.2	4.1	5.2	4.2
50%	DA	69	71	73	75	71	72
	UDI	65	66	68	69	67	67
	Supplementary	30	28	25	23	28	26
	Exceeded	3.7	4.7	4	5	3.7	4.7
40%	DA	80	78	77	75	78	76
	UDI	70	69	68	67	68	68
	Supplementary	18	20	21	23	20	22
	Exceeded	9.4	8.4	9.1	8	9	8.1

OBSERVATION

Analyzing different daylighting metrics it is observed that the 65% window to wall ratio along with a curved skylight with translucent glass has the highest UDI and daylight autonomy making it the favorable ratio for West facing classrooms. They have the most uniform light distribution.

SHADING

The daylight entering the classroom through the west facade is mostly diffused. Since there is no direct beam sunlight entering the room no shading is required for this pattern.

GLAZING TYPE

Lower window with transparent glass, upper window with translucent glass and translucent glass for skylight helped in bringing ample diffused daylight. The Daylight distribution is also uniform throughout the classroom.

FINAL PATTERN TYPOLOGY 4B

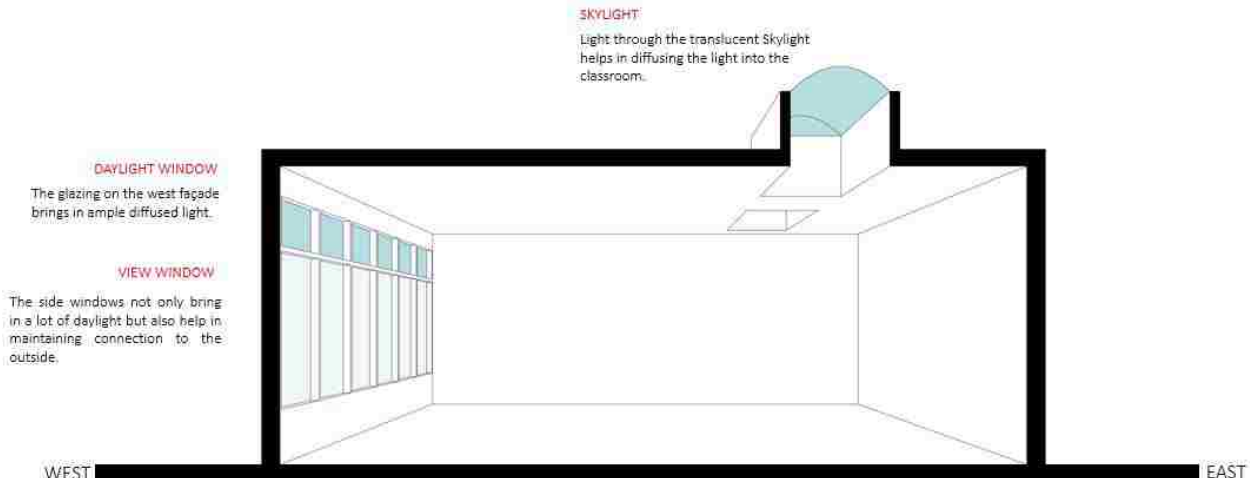


Image rr : *Final Classroom Pattern for Typology 8*

CHAPTER V

APPLICATION

The eight classroom patterns based on Daylighting in the previous chapters have been designed as an individual entity. The next step was to see the effectiveness of these patterns when they are brought together on a site with existing site conditions.

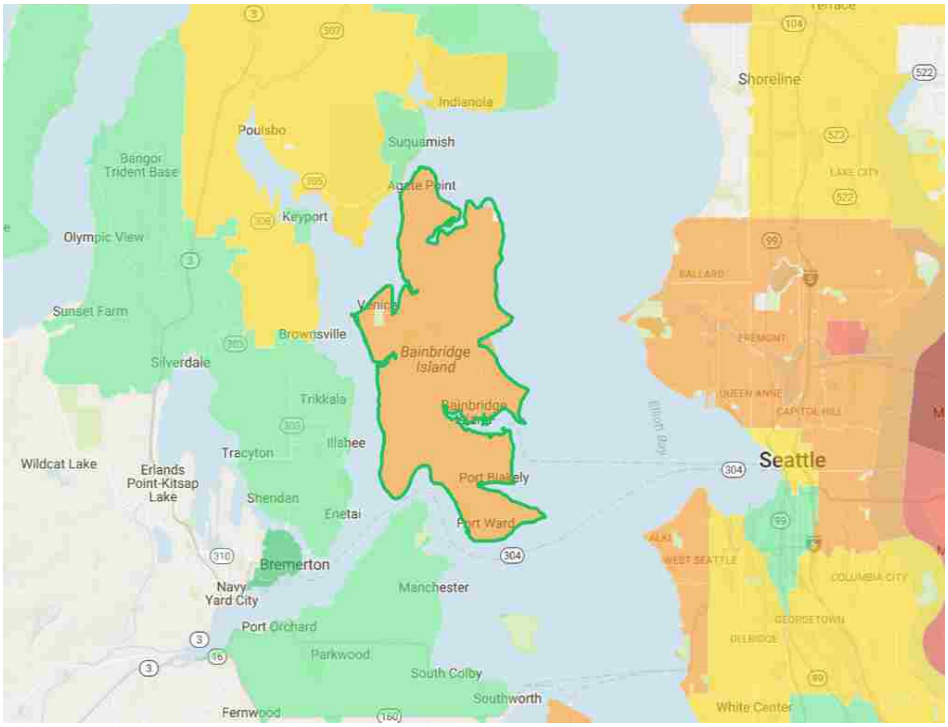


Image ss : *Location Map for Bainbridge island*

To validate the design of the classrooms a site is selected at the Bainbridge island. The site is of an Elementary School. The site is relatively flat with not many undulations. There is a lot of foliage around the periphery of the site.

The goal was to organize different spaces depending on the importance of daylight in that space. Keeping daylighting criterion in mind two schemes were developed where classrooms were arranged so that they have access to daylight. The two proposals have classrooms oriented in North-South and East-West direction. The access to the site is from the West. The north is oriented upwards. The proposed school building is oriented in the E-W direction. The classrooms

OPTION 1 / NORTH SOUTH ORIENTATION

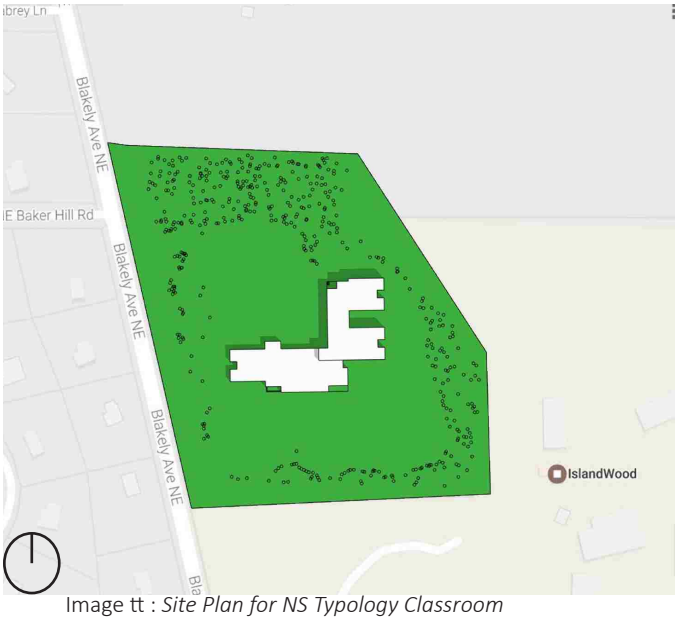


Image tt : *Site Plan for NS Typology Classroom*

The proposal has all the classrooms facing North and South. The classrooms have been laid out on the first floor as well as the second floor. The classroom wings have been spaced apart from each other to allow solar access to the classrooms that are facing inwards.

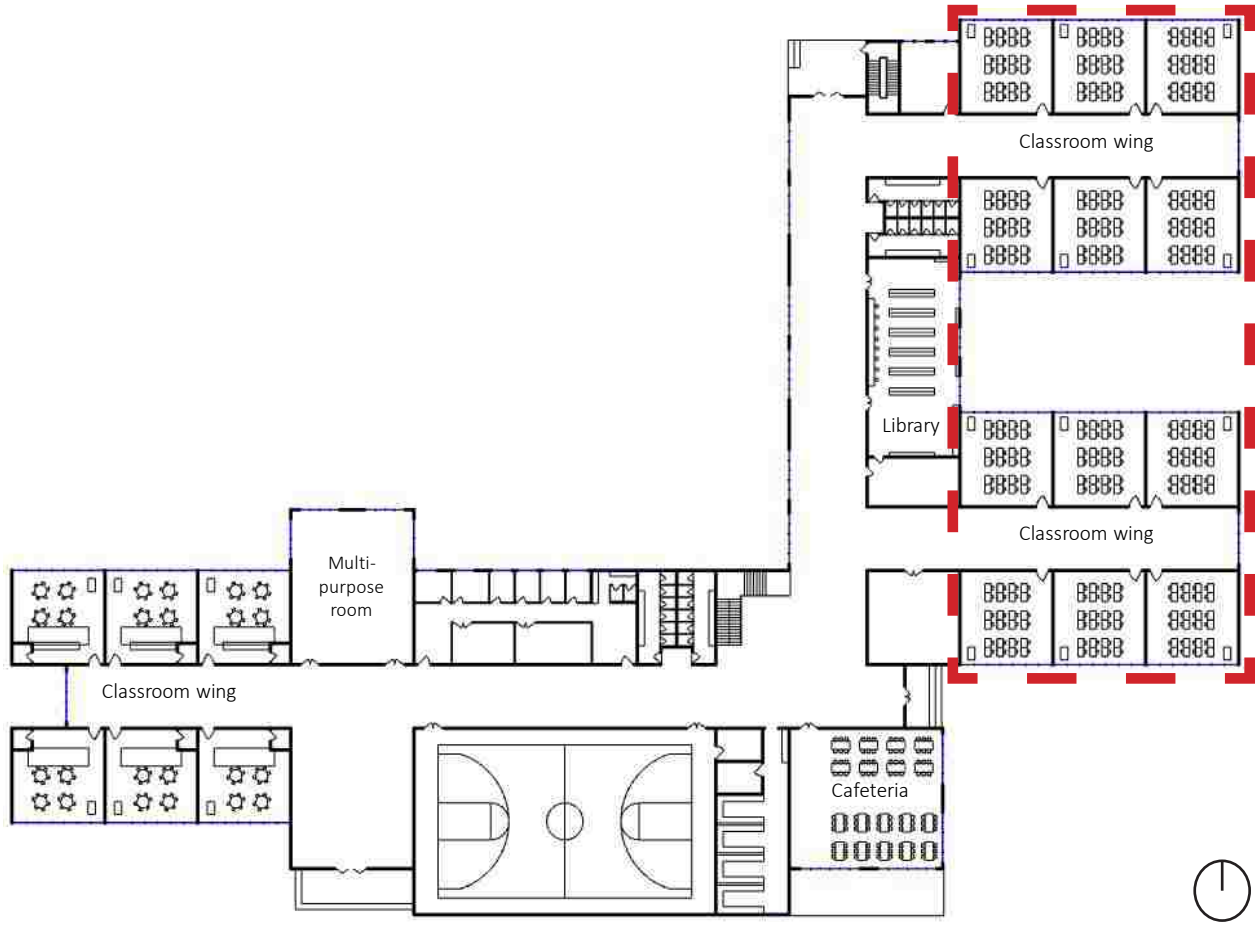


Image uu : First Floor Plan

Image uu : First Floor Plan

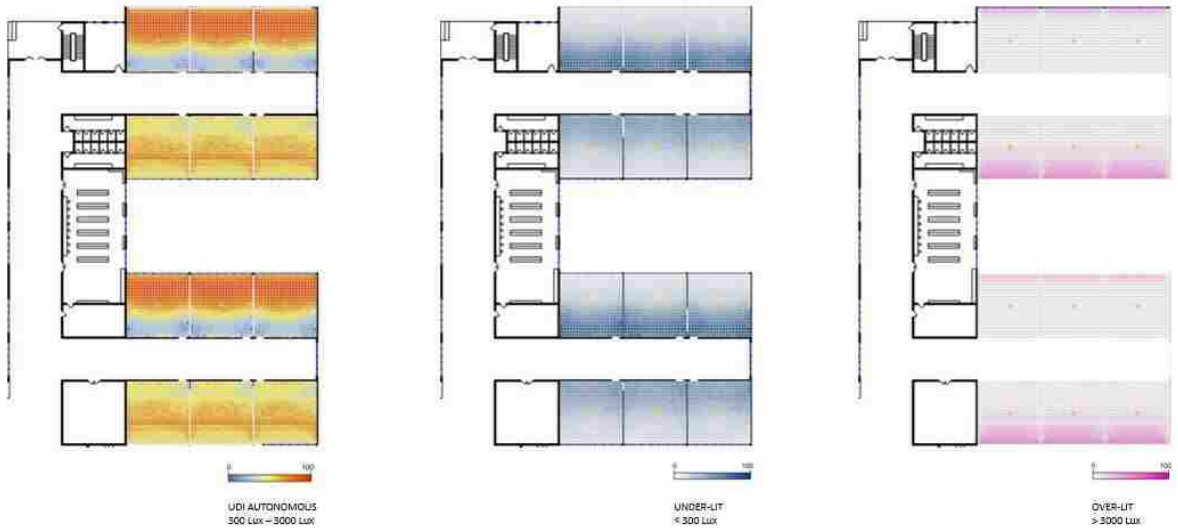


Image ww: False color Image for First floor plan

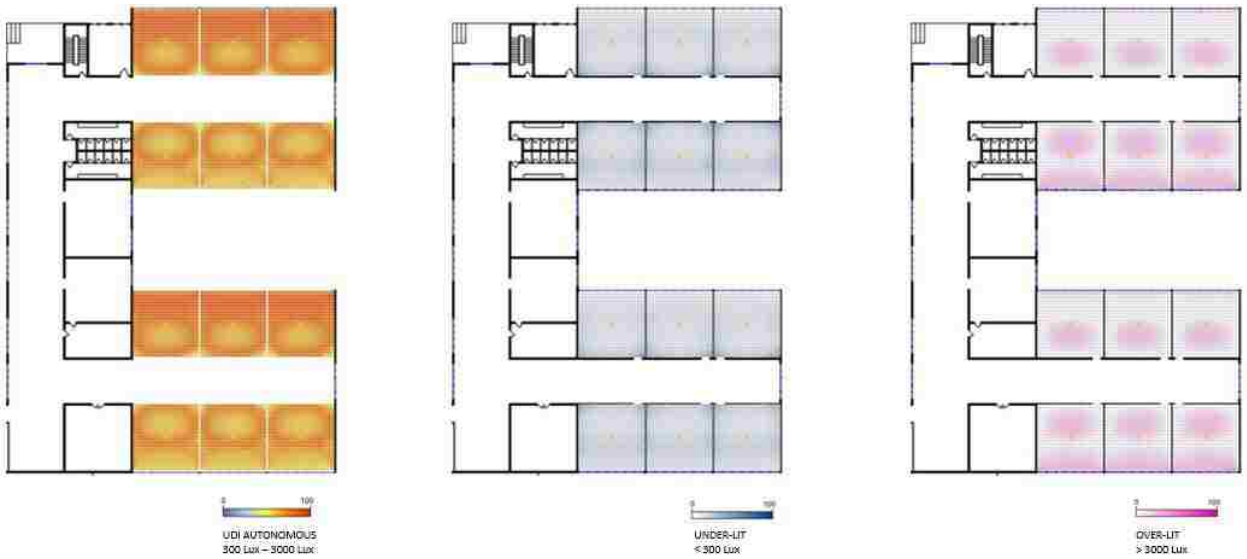


Image xx : False color for Second floor plan

OBSERVATION

When the different classroom patterns were arranged together on a site, the patterns work really effectively.

There were small deviations from the actual patterns which were caused mostly because of the over shadowing from the new or the existing structures on the site.

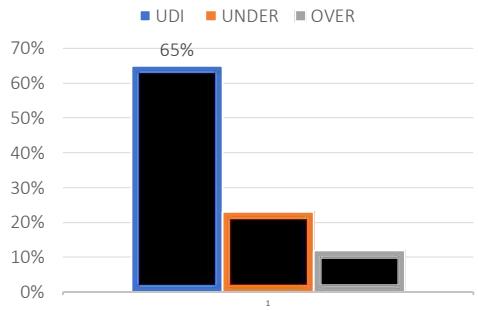
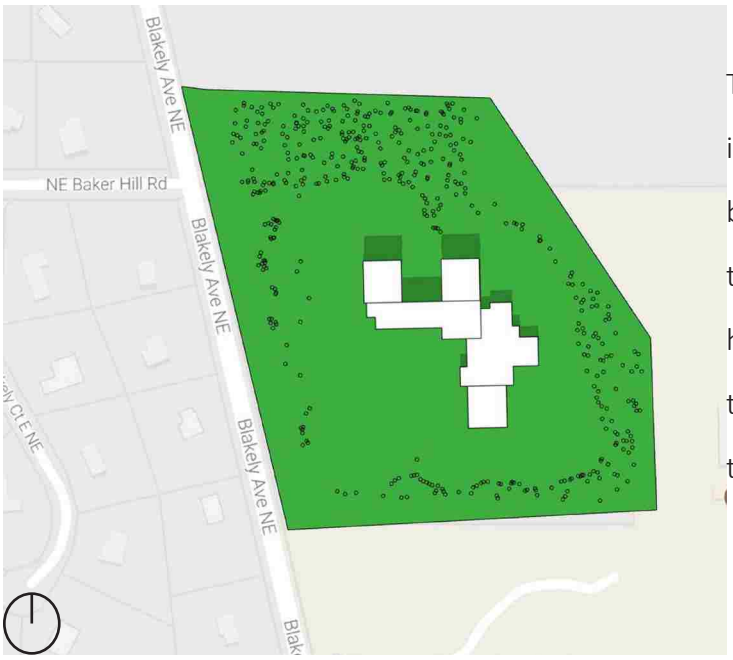


Image yy: *Graph displaying the different illuminance for First Floor*

The classrooms were day-lit in the optimum range for 75 % of the year during occupied hours during a year. This also helped in reducing the energy loads of the building considerably thus proving the patterns to be efficient.

OPTION 2 / EAST-WEST ORIENTATION



The proposal has all the classrooms facing East and West. The classrooms have been laid out on the first floor as well as the second floor. The classroom wings have been spaced apart from each other to allow solar access to the classrooms that are facing inwards.

Image zz : Site Plan for EW Typology Classroom

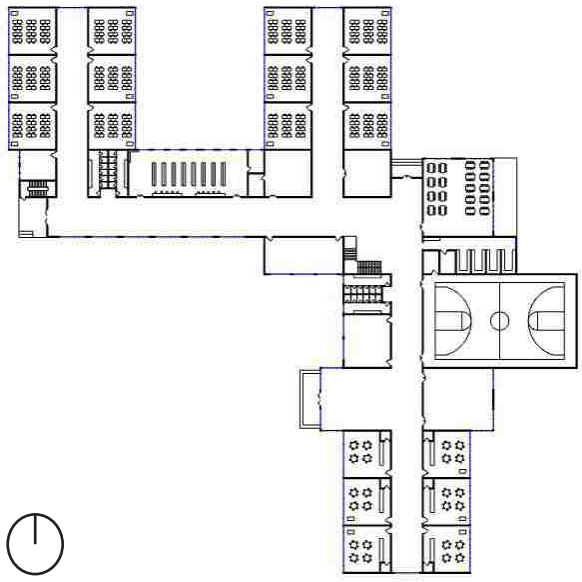


Image aaa : First Floor Plan

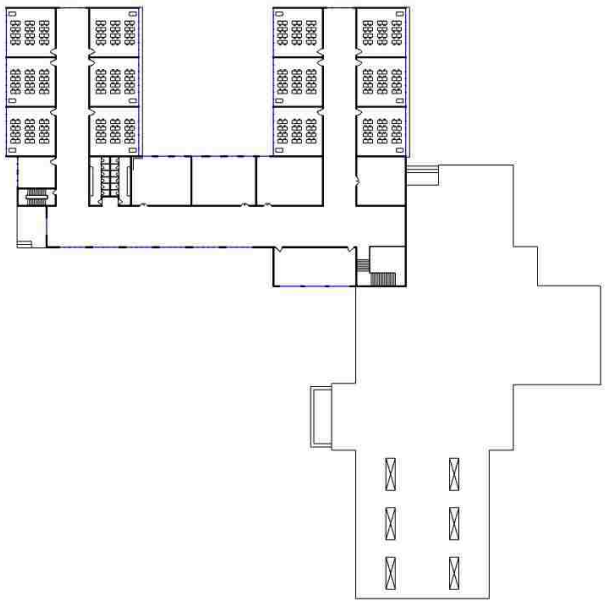


Image bbb: Second Floor Plan

APPLICATION

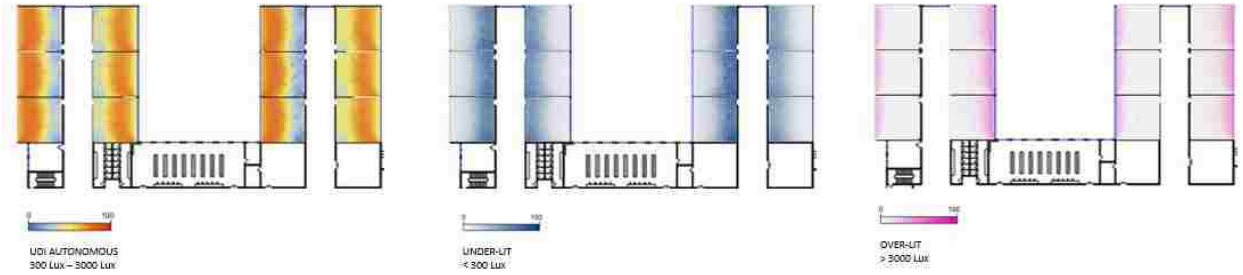


Image ccc: *False color for First floor*

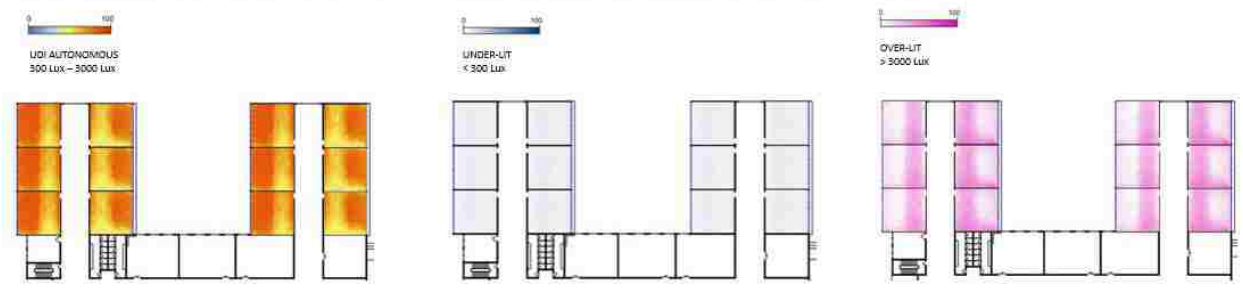


Image ddd : *False color for Second floor*

OBSERVATION

When the different classroom patterns were arranged together on a site, the patterns work really effectively.

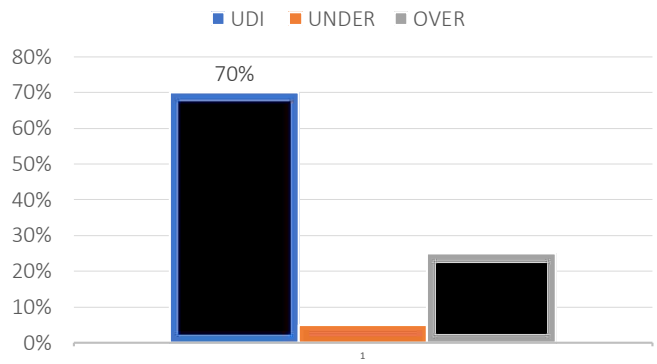


Image eee: *Graph displaying the different illuminance*

There were small deviations from the actual patterns which were caused mostly because of the over shadowing from the new or the existing structures on the site.

The classrooms were day-lit in the optimum range for 95 % of the year during occupied hours during a year. This reduced the electrical energy loads of the classrooms to almost negligible.

CONCLUSION

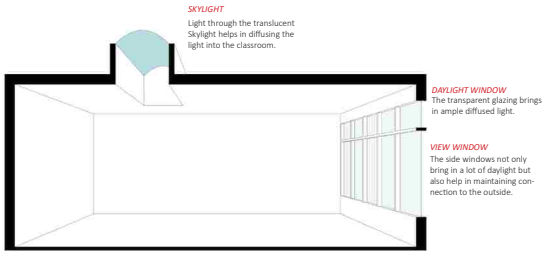
The idea of the thesis was to create a pattern language for classroom spaces based on daylighting for elementary schools. The process started with exploring different 21st century school models and analyzing the distinct features that made them energy efficient. Of all the features the one that stood out the most in these 21st century school models was daylighting. Daylighting had a huge role to play on the student performance, their decreasing absenteeism and balancing the circadian rhythm, thus it became my area of focus.

The goal of the research was to dive into different daylighting strategies and to come up with classroom patterns that are passively lit. The research is concluded with 8 different classroom patterns . These classroom patterns were designed as separate entities. The aim was to achieve uniform daylight in the space to perform visual tasks with minimal discomfort as possible.
The thesis helped in defining design strategies that can be applied to different typologies to achieve daylighting goals.

The proposed classroom patterns meet the goals outlined previously in the research. These goals were set to passively day light the classroom. To see the effectiveness of the patterns an outline of an elementary school was designed at Bainbridge Island and the proposed classroom patterns were incorporated in the design. Since the patterns were designed as individual entities it was interesting to see how the space changed with surrounding building in the vicinity. Various daylighting metrics were used to confirm the authenticity of the patterns. It was observed that the patterns worked effectively with slight deviation which was caused by over shading of immediate surroundings. Of the two option 2 turned out to be a better composition where the classrooms were facing east and west as the space was daylit for 95 percent of the year as compared to the North and South orientation. Therefore the strategies developed can be used to design classroom spaces to optimize daylight.

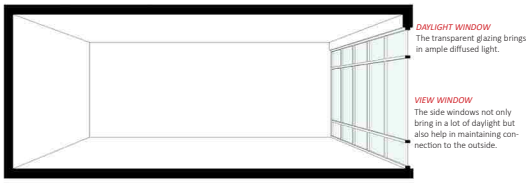
Following are the 8 classroom patterns :

TYPOLOGY 1B



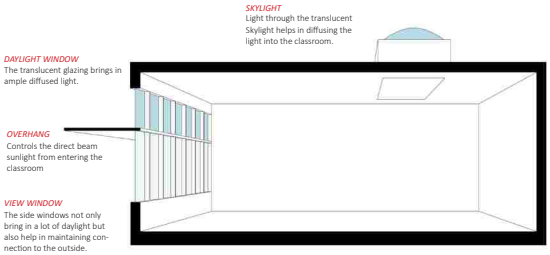
W/W RATIO: 65%
TOP LIGHTING: 5% of Floor Area
CLEAR DAYLIGHT WINDOW
CLEAR VIEW WINDOW

TYPOLOGY 1A



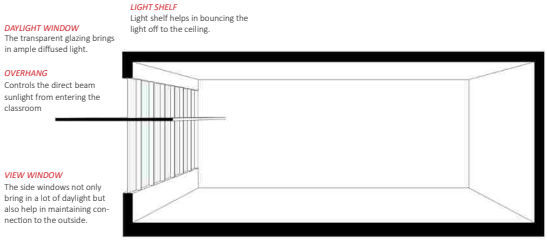
W/W RATIO: 75%
CLEAR DAYLIGHT WINDOW
CLEAR VIEW WINDOW

TYPOLOGY 2B



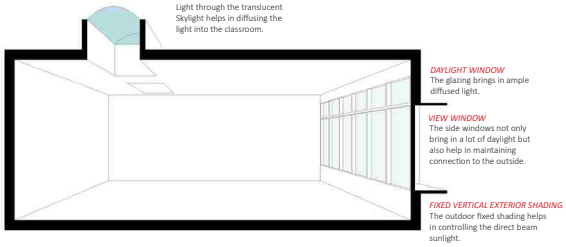
W/W RATIO: 65%
TOP LIGHTING: 10% of Floor Area
TRANSLUCENT DAYLIGHT WINDOW
CLEAR VIEW WINDOW
OVERHANG FOR VIEW WINDOW

TYPOLOGY 2B



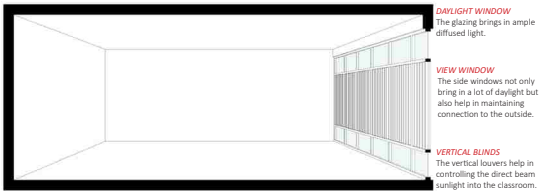
W/W RATIO: 65%
CLEAR DAYLIGHT WINDOW
CLEAR VIEW WINDOW
LIGHT SHELVES
OVERHANG FOR EXTERIOR WINDOWS

TYPOLOGY 3B



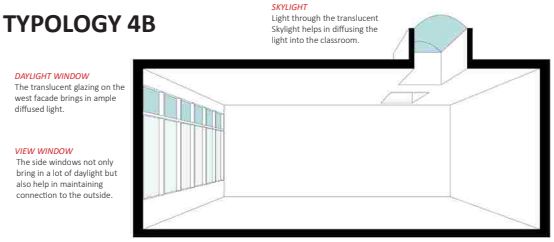
W/W RATIO: 65%
TOP LIGHTING: 10% of Floor Area
CLEAR DAYLIGHT WINDOW
CLEAR VIEW WINDOW
VERTICAL SHADING FOR VIEW WINDOW

TYPOLOGY 3A



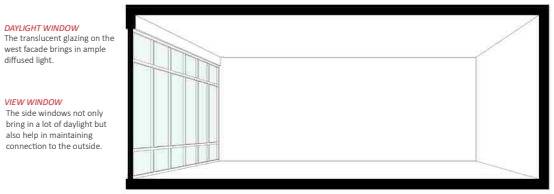
W/W RATIO: 75%
CLEAR DAYLIGHT WINDOW
CLEAR VIEW WINDOW
VERTICAL LOUVERS FOR VIEW WINDOWS

TYPOLOGY 4B



W/W RATIO: 65%
TOP LIGHTING: 10% of Floor Area
TRANSPARENT DAYLIGHT WINDOW

TYPOLOGY 4A



W/W RATIO: 75%
CLEAR DAYLIGHT WINDOW
CLEAR VIEW WINDOW

Image fff: *Final Classroom patterns*