An investigation of sustainable strategies and the design considerations for the institutional buildings to get better daylighting performance.

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Abstract

The paper deals with the understanding of sustainable strategies for institutional buildings concerning daylight in Warm and Humid regions. The aim is to (i) assess the Daylight aspect of Institutional Buildings and implementing design interventions to obtain uniform daylight. (ii) To understand concepts, techniques, metrics, and design considerations for day lighting. (iii) To establish a need for daylight for psychological wellbeing and visual comfort. Daylight is a vital element in Architecture and our daily lives. It enables us to visualize the space around us. It is also the main factor that affects visual comfort hence plays a major impact on the human psyche. The productivity increases when the user has a healthy psyche and is visually comfortable. Thus, it is vital to focus on day lighting in Institutional spaces as this is where young minds are molded.

Keywords: *Daylight, Daylight Systems, Fenestrations, Institutional Buildings, Sustainability.*

1. Introduction

1.1. Background

Day lighting is renowned for its many aesthetic and health benefits by designers and researchers alike. Scientists at the Lighting Research Centre (LRC), in Troy, N.Y., for example, have reported that day lit environments increase occupant productivity and comfort, and provides mental and visual stimulation necessary to regulate human circadian rhythms.

Utilizing natural light can lead to substantial energy savings.[1] Electric lighting in buildings consumes more than 15 percent of all electricity generated in the United States, according to the U.S. Department of Energy and the U.S. Energy Information Administration.[1] Spaces outfitted with daylight-sensing controls can reduce the energy used for electric lighting by 20 % to 60 %.

“Daylight can also be too much of a good thing,” says Joseph Park. [1] A building that has aggressive day lighting goals but is poorly operated will likely use more energy and might subject its occupants to excessive glare and thermal stress. On the other hand, Lisa Heschong, managing principal at TRC Companies says that when she interviewed workers in daylit retail, commercial, and education spaces, “they consistently report how they love working there.”

In a 1999 study, Day lighting in Schools: An Investigation into the Relationship between Day lighting and Human Performance," commissioned by the Pacific Gas and Electric Company, found a high correlation between schools that reported improvements in student test scores—upwards of 10% & those that reported increased daylight in the classroom. The findings sparked discussion on the influence attributable to day lighting, or the day lighting effect size.

1.2. Daylight and the Circadian Cycle

The biological processes that regulate our sleep-wake cycle make up our circadian system. Primarily through the use of the neuro-hormone melatonin, our circadian system regulates our patterns of alertness and sleepiness. Without exposure to normal 24-hour light-dark cycles, a person's sleep-wake cycle can stray by as much as two hours per day. The cumulative effect of this can be significant. An imbalanced sleep-wake cycle may produce advanced or delayed sleep-phase disorders and lead to chronic sleep debt.

1.3. Integrating Daylight with Design

While daylight is a variable, often unpredictable, a light source with a spectrum that depends on the solar position and sky conditions, it is also rich in the short-wavelength portion of the visible spectrum found to support both alertness & circadian cycle. As a result, daylight in buildings may support human health and well-being, particularly for people in northern latitudes who occupy areas near a window or other daylight sources. [1] At the same time, it is important to remember that it is the daily variation associated with the day-night cycles that support human health.

Designers can glean two points from this trove of research.

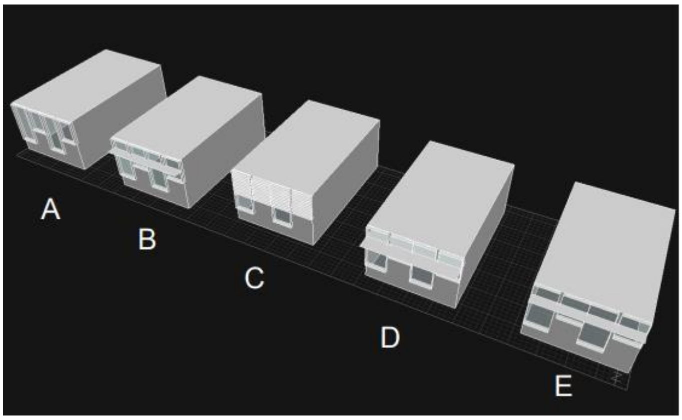
- Day lit spaces hold the potential to yield substantial benefits, including increased energy savings and improvements to human health and productivity.
- Several important factors ranging from design to installation and operation must be carefully addressed to realize these benefits.

2. Methodology

Source: Author
Figure 1. Methodology

2.1. Study to Find Daylight Metric which Best Portrays Daylight Performance

2.1.1. Academic Building - South-facing Classrooms:



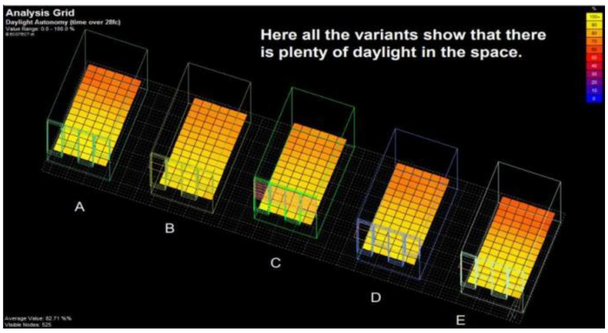
Source: www.sustainable-performance.org
Figure 2. Five Variants of windows for Classrooms

1. Variant A: "No Shade" Same as E but without sun shelf.
2. Variant B: "Different Glass" 60% visible transmittance rather than 72%.
3. Variant C: "Horizontal Louvers" 6" deep louvers at 6" O.C. for a portion of windows above 7'.
4. Variant D: "Interior/Exterior Shelf" 24" exterior shelf plus 36" interior shelf at 10'.
5. Variant E: "As Designed" 3' or 7' sill, 12'-6" head, 24" deep exterior sun shelf at 10'.

2.1.2. Issues to consider while providing daylight:

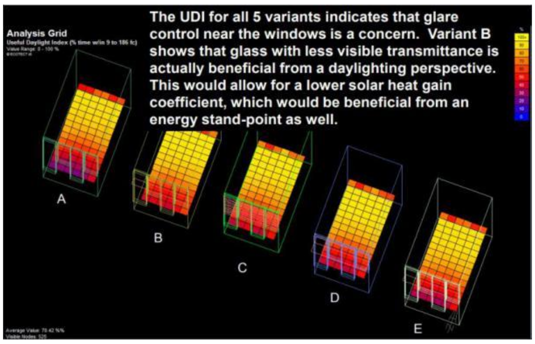
- Shading and sun control
- Visual requirements (glare, view, privacy)
- Thermal comfort
- Security issues
- Color effects
- Energy requirements
- Daylight performance

2.1.3. Daylight Autonomy (DA):



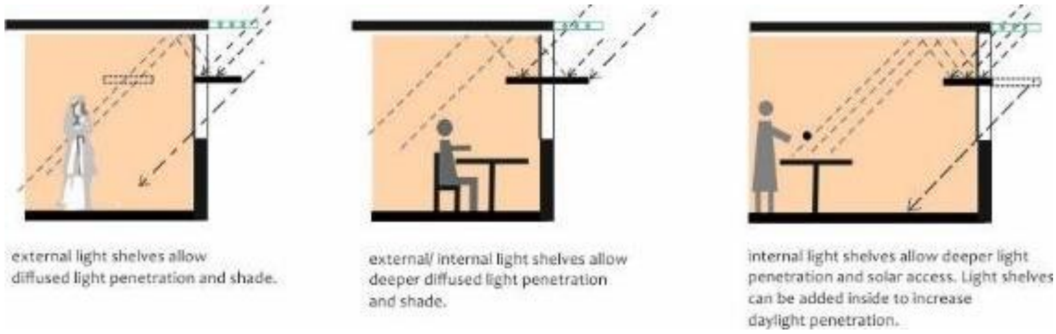
Source: www.sustainable-performance.org
Figure 3. Light Contour for Daylight Autonomy

2.1.4. Useful Daylight Illuminance (UDI):



Source: www.sustainable-performance.org
Figure 4. Light Contour for Useful Daylight Illuminance

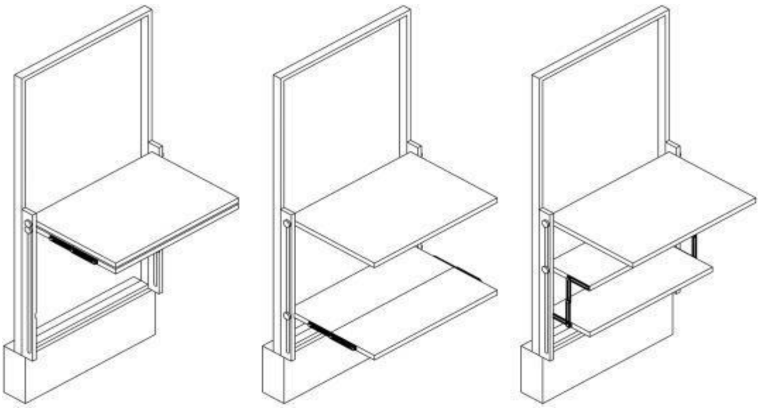
2.1.5. Light Shelves:



Source: http://www.nzeb.in/wp-content/uploads/2015/07/LIGHTSHELVES.jpg
Figure 5. Light Shelves

- Increase daylight penetration.
- Reduces the need for artificial lighting in buildings.
- Light shelves make it possible for daylight to penetrate the space up to 2.5 times the distance between the floor and the top of the window.[2]

2.2. Dynamic Light Shelves System



Source: https://ars.els-cdn.com/content/image/1-s2.0-S0360132316302372g1
Figure 6. Dynamic Light Shelves

Shelves are movable, so direct light glare can be prevented, and reaching of sunlight into the deep of the room is provided.

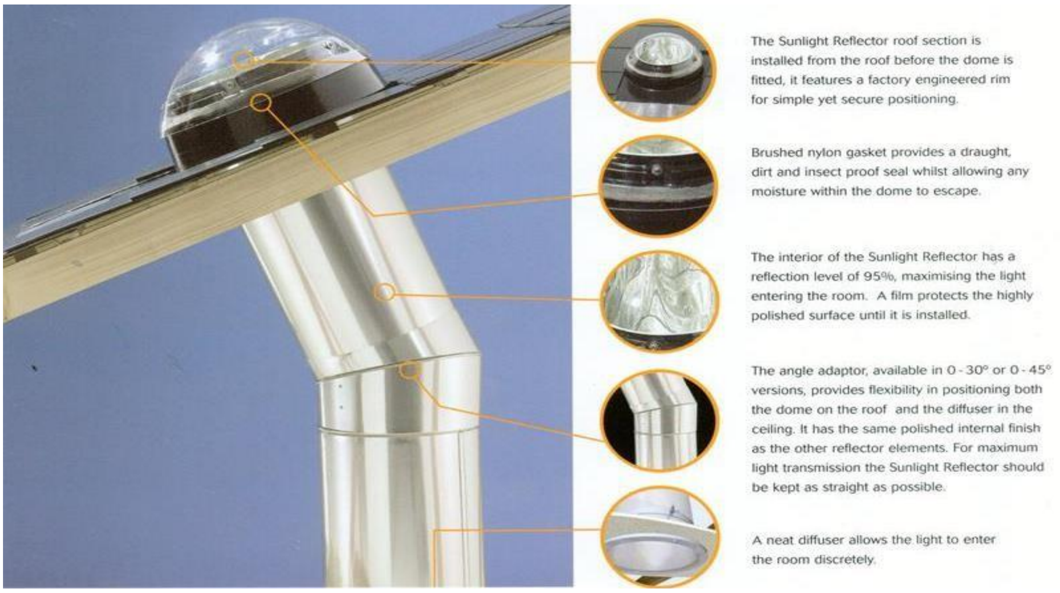
There are two types light shelves,

- Automatic Systems: a microcomputer arranges the positions and angles of the shelves according to seasons to provide efficient illumination.
- Manuel Systems: users arrange the position of the shelves according to seasons, months, etc. according to the sun's position.

2.3. Lighting systems

2.3.1. Light tubes:

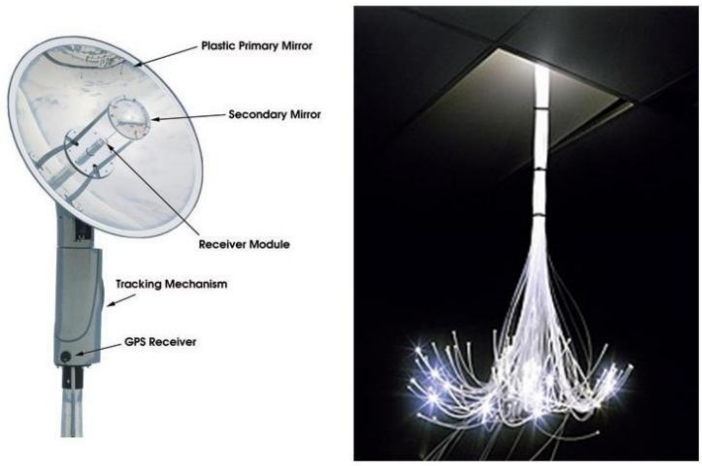
It Emits daylight from one optical staff and transmits to the spaces. This system is successful at especially deep spaces such as large office buildings. [3]



Source: http://www.dry-it-out.com/SL-355SLATE-45

Figure 7. Light Tubes

2.3.2. Fiber optics:



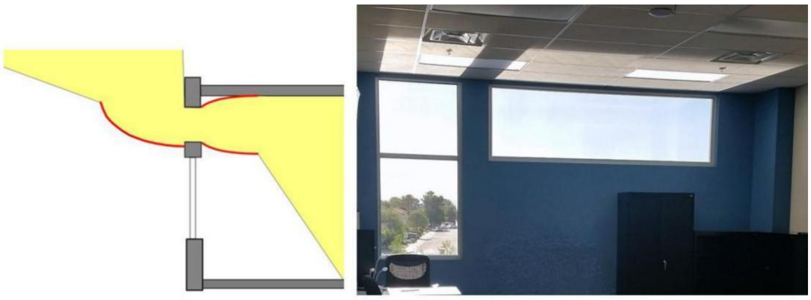
Source: i.pinimg.com/originals/a7/73/f4/a773f42104789affb0d60c37fefe78c2

Figure 8. Fiber Optic Daylight System

Fiber optics are optical specified fibers that can transmit and lead the light rays through the long ranges. [3] Solar panels or heliostat units that are positioned on the rooftops, collect daylight that is transmitted with fiber optic cables, then daylight is transmitted to light tubes.[3] These tubes are directly related to the special lighting source to illuminate the spaces during the day.

2.3.3. Anidolic Systems:

The working principle is to absorb sunlight with a glass semi optics unit than transmitting to the ceiling system. This system has no particular collector or distributor.



Source: https://en.wikipedia.org/wiki/File:Zenithal_anidolic_example1.jpg
Figure 9. Anidolic System

2.4. Design Considerations
2.4.1. Contemplating Human Factors:

The most important aspect of a good day lighting design is to understand how it affects human nature. In addition to the energy and maintenance benefits, a well-lit school may help in:

- Improving student performance.
- Creating a healthier indoor environment.
- Increase in attendance.

2.4.2. Orientation and form for day lighting:

Buildings can be located and oriented to take advantage of the sun's movement throughout the day, and seasonal variations as well.

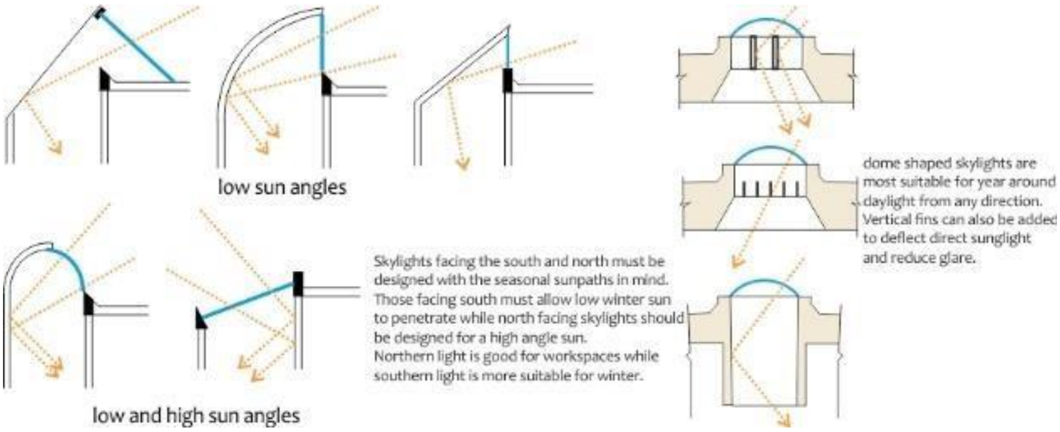
2.4.3. Windows:

The amount of daylight that enters a room depends on the window location and its dimensions. The treatment for the window size, height, and glazing should be done separately. [4] Derive Maximize southern exposure and optimize northern exposure.

2.4.4. Top light systems:

Top lighting is an effective day lighting solution for wide buildings where side lighting cannot be used for adequate lighting of the deeper areas of the floor plate. [4] To reduce glare, skylights must be designed with reflective surfaces that redirect direct sunlight into space.

Source: http://www.nzeb.in/wp-content/uploads/2015/07/toplighting.jpg
Figure 10. Top Light Systems



2.4.5. Appropriate Glazing:

Windows should be made of high-quality construction, and include the appropriate glazing for the particular application.[5] A clear distinction between glazing that is incorporated for views and ventilation and that which provides day lighting. In all cases, where windows are used specifically for day lighting, clear glass has an advantage in over glazing with a low-E coating. [5] Due to a 10% to 30% reduction in visible light transmission characteristic of most low-E coatings, 10% to 30% more glass would be required to produce the same day lighting benefit. [6]

Application	Exposure	Type
View Glass (non-daylighting apertures)	South North East/West, unshaded East/West, shaded	Clear double, low-e Clear double, low-e Tinted double, low-e Clear double, low-e
Windows above lightshelves	South	Clear double, glass or acrylic
High windows above view glass	North	Clear double, glass or acrylic
Roof monitor	South	Clear double, glass or acrylic
Blinds-between-glazing	South	Clear double, glass or acrylic

Source: Guide for day lighting schools (2004) a comprehensive brochure addressing key design considerations for using day lighting in schools.
Table 1. Glazing Options as per Orientation

2.4.6. Glass to floor area ratio:

Until detailed day lighting analysis is conducted, the basic thumb rule can help in determining the right amount of day lighting glazing for particular systems.

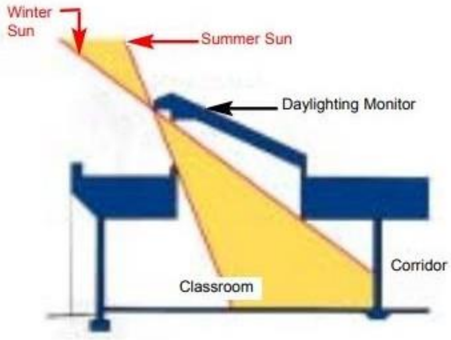
	Classroom (% of floor space)	Gymnasium (% of floor space)
• South-facing roof monitor	8% to 11%	5% to 8%
• South lightshelf	8% to 11%	
• South lightshelf w/blinds between glazing	15% to 20%	
• North-facing roof monitor	12% to 15%	7% to 10%
• High, north transom glazing	15% to 20%	

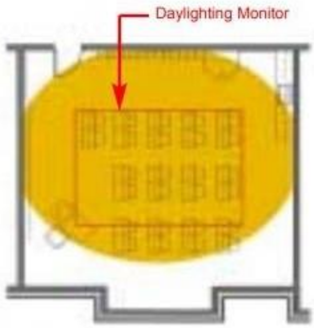
Source: Guide for day lighting schools (2004) a comprehensive brochure addressing key design considerations for using day lighting in schools.

Table 2. Glass-To-Floor area Ratios

2.4.7. South-facing Roof Monitors:

Roof monitors that incorporate vertical south-faced glazing, properly sized overhangs, and interior baffles have an advantage.

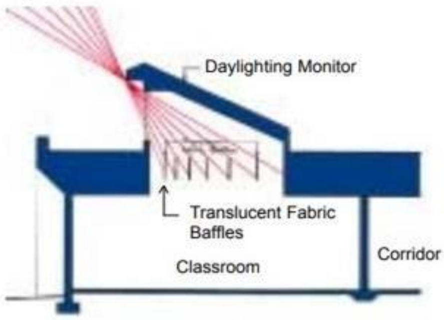




Source: Guide for day lighting schools (2004) a comprehensive brochure addressing key design considerations for using day lighting in schools.

Figure 11. Roof Monitor

2.4.8. Translucent baffles to reduce contrast:



Source: Source: Guide for day lighting schools (2004) a comprehensive brochure addressing key design considerations for using day lighting in schools.

Figure 12. Roof Monitor Section with Baffles

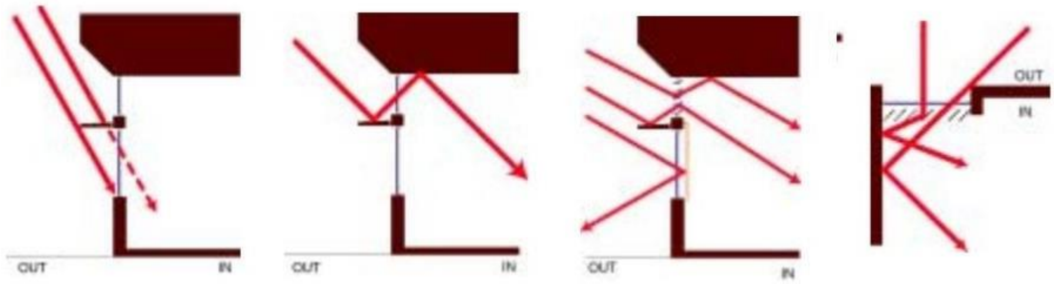
Light-colored translucent baffles not only reflect the sunlight into space but also help eliminate contrast from one side of the baffle to the other. [7]

2.4.9. South-facing Light shelves:

Light shelves incorporated into south glazing strategies are typically the next best option in that they:

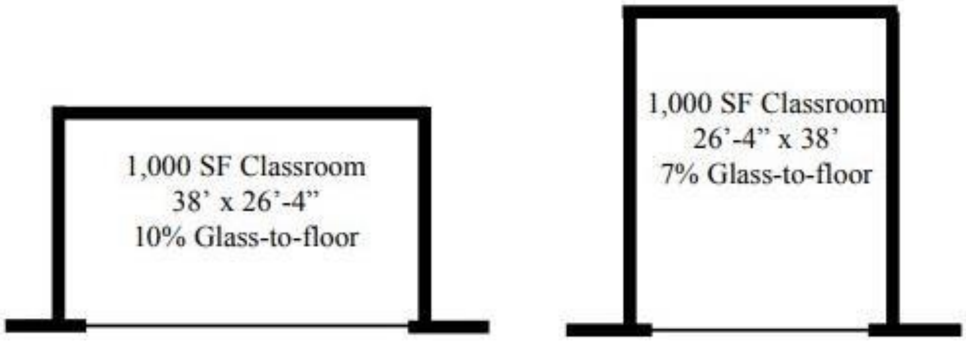
- Can be used in multi-story situations.
- Can bounce sunlight to the back of most school classrooms.
- Help shade view glass located below the light shelf and [7]
- Typically cost less than monitor strategies.

2.4.9.1. Bounce light deeper into space:
A light shelf made of a highly reflective material will bounce the sunlight that strikes the top of the surface deep into the building. The reflected sunlight will hit the ceiling and bounce down into the room. Light shelves on northern exposures have no advantage.



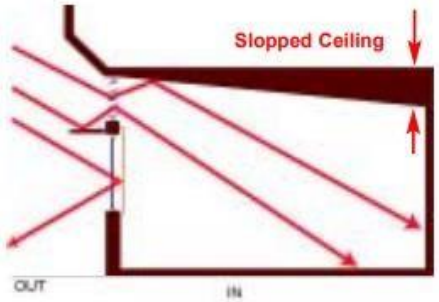
Source: Source: Guide for day lighting schools (2004) a comprehensive brochure addressing key design considerations for using day lighting in schools.
Figure 13. Functions of Light Shelves

2.4.9.2. Room length for maximum glazing:
The lengthier the classrooms and offices are in the east-west direction, the more opportunity to achieve an adequate day lighting strategy that employs light shelves.



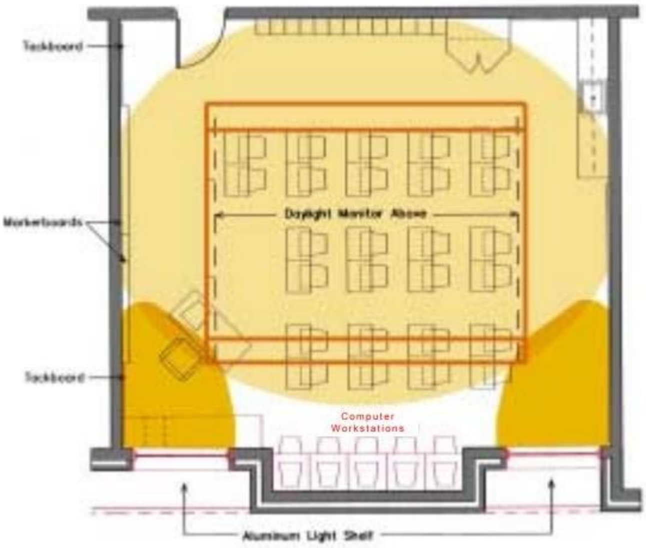
Source: Source: Guide for day lighting schools (2004) a comprehensive brochure addressing key design consideration for using day lighting in school.
Figure 14. Disadvantage of elongated Room

2.4.9.3. Sloped ceiling from the top of the light shelf:
To maximize the ability to bounce light deep into a space using a light shelf, you should consider the advantages of sloping the ceiling from the top of the south-side light shelf to the back of the room (north wall of space). The efficiency is increased by 10% or more when compared to a flat ceiling.



Source: Source: Guide for day lighting schools (2004) a comprehensive brochure addressing key design considerations for using day lighting in schools.
Figure 15. Effect of Sloped Ceiling

2.4.9.4. Light shelves to complement roof monitors:
Light shelves on south-facing windows can be effective in complementing the daylight provided by the roof monitors. If one window is present on each end of the south wall, the day lighting within the space will be balanced.



Source: Source: Guide for day lighting schools (2004) a comprehensive brochure addressing key design considerations for using day lighting in schools.

Figure 16. Light Shelves complementing Roof Monitors

2.5. Energy ramification
All the heat produced by the lights as well as the heat created by sunlight will overheat the space, requiring more air conditioning. If designed correctly, a day lighting strategy can reduce:

- Electricity for lighting and peak electrical demand;
- Cooling energy and peak cooling loads;
- Maintenance costs associated with lamp replacement;
- Electrical service to the building; and, in some cases,
- The number of installed lighting fixtures in the school.
- No more radiation is allowed to enter the building than is required to meet your foot-candle objectives;
- Properly sized overhangs limit the radiation to optimal amounts; and
- The lights, with the use of photo sensors, are automatically dimmed or switched off.

2.6 General Recommendations for Day lighting Options

2.6.1 Minimize contrast:
The success of day lighting strategy will be determined, to a great degree, by the amount of contrast that exists within space. The design should attempt to eliminate contrast between bright surfaces and darker surfaces by avoiding bright, visually exposed windows. Roof monitors help considerably in bringing more uniform light into space since not all the day lighting apertures are located on one wall.

2.6.2 Light colour for Interior finishes:
When considering finish surfaces, light colours in the sky well, ceiling, wall, furniture & floor are always optimum to reflect the daylight throughout the space. Darker surfaces will require more glazing to achieve the same net effect.

2.6.3 High reflective ceiling tile:
Consider a ceiling tile or surface that has a high reflectivity. Make sure to account for any fissures in acoustical tiles and how this will impact the amount of light absorbed. The colour of the tile does not dictate its reflectance.

3. Case study

3.1 Identifying the problem
Case description: The building is oriented in the east-west axis to optimize a position as the sun path can have a significant influence on the level of illuminance on the North side of the block.

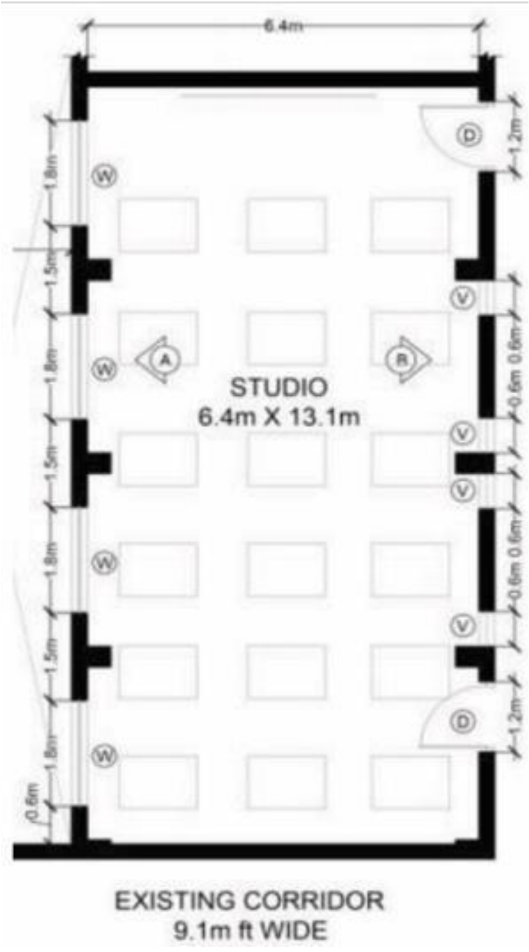


Figure 17. Case Studio Plan

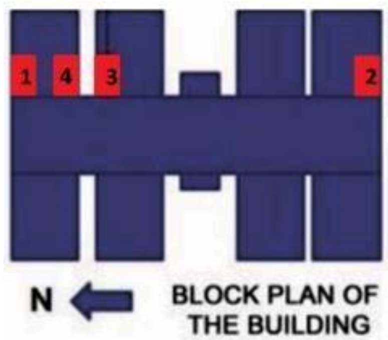


Figure 18. Key Plan

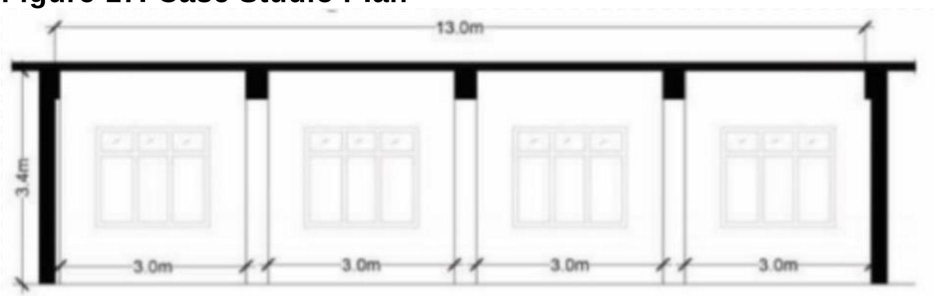


Figure 19. Side A elevation

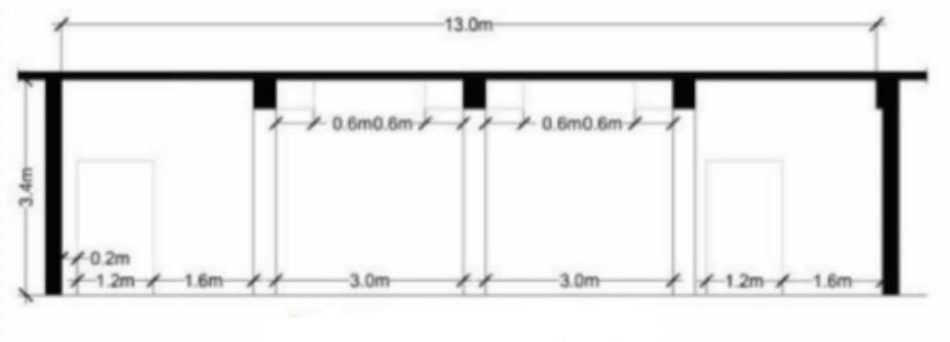


Figure 20. Side B elevation

As is in Fig.17 (Plan of the studio), the studio is considered in SPA Vijayawada. The studio measures 6.4m x 13.1m (83.83m2) having a clear ceiling height of 3.4m. The light comes from four windows of size 1.8m x 1.6m.

The window to floor area percentage is 13.2 %. According to ―Indian standard, Code of Practice for Day lighting of educational building, recommended illumination level on work areas for educational buildings is:

1. Lux Level – 150 to 300 lux
2. Daylight factor – 1.9 to 3.8
3. Reflection factor for Ceiling – 0.8 to 0.7
4. Reflection factor for Walls – 0.7 to 0.5
5. Reflection factor for floors – 0.35 to 0.25

Four cases are considered to evaluate the daylight performance:

Case 1: Studio with windows on North facade (No obstruction)
Case 2: Studio with window on South facade (No obstruction)
Case 3: Studio with window on North facade (Towards OTS)
Case 4: Studio with window on South facade (Towards OTS)

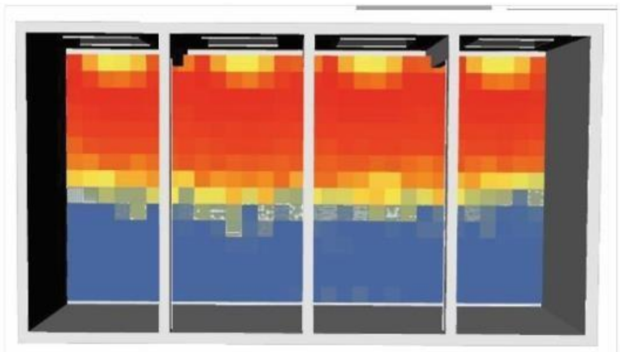


Figure 21: Case 1. Daylight Stimulation

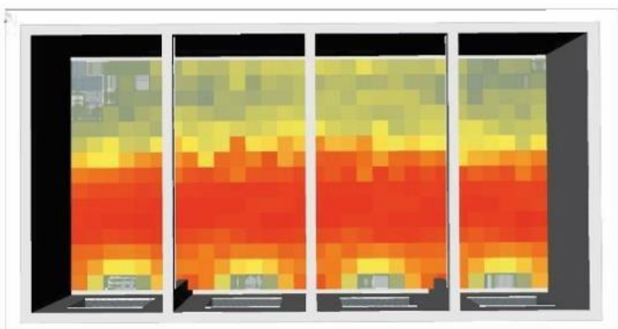


Figure 22: Case 2. Daylight stimulation

Figure 23: Case 3 Daylight stimulation

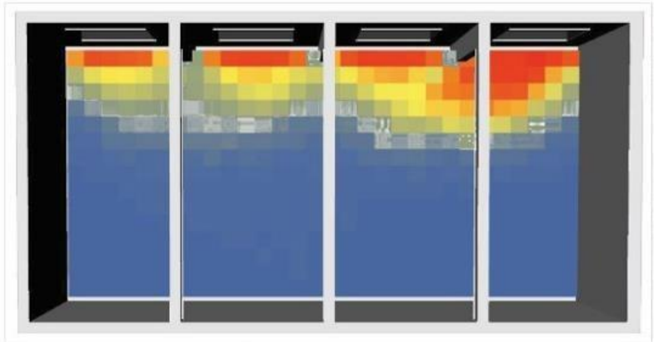


Figure 24: Case 4 Daylight stimulation

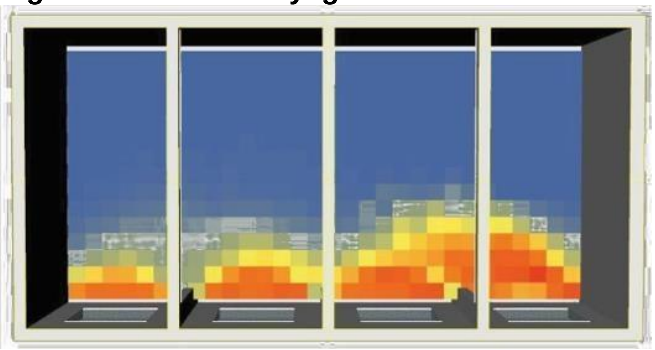


Figure 21, Case 1, proves that the studio with windows on the North facade with no obstruction gives the best amount of daylight into space.

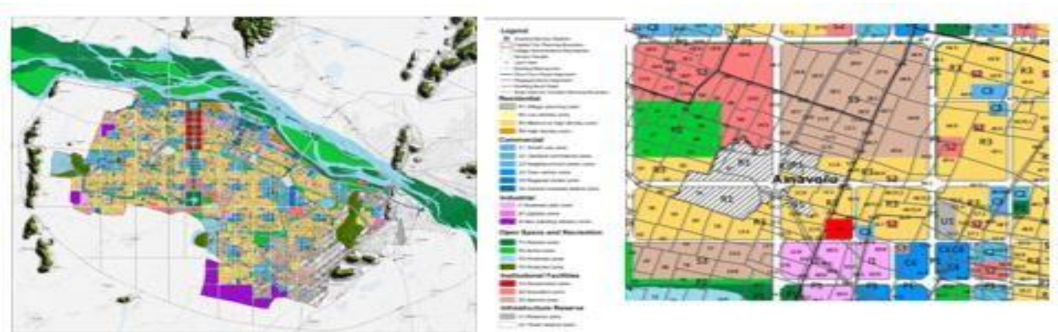


Figure 25. Amravati Master Plan & Landuse of surrounding of site

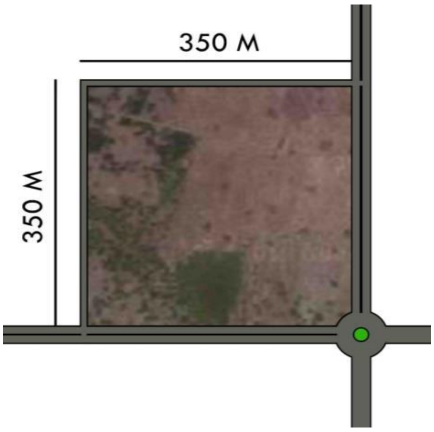


Figure 26. Site

3.2 Site Analysis

The National Institute of Design, Vijayawada is established in September 2015 as an autonomous Institute under the DIPP, Ministry of Commerce and Industry, Government of India. It is situated temporarily in Acharya Nagarjuna University on Guntur - Vijayawada highway (NH 16) as a transit campus before moving to permanent campus to come up in Amravati, new Capital City of Andhra Pradesh.

4. Conceptual Development

4.1 Form Generation

4.1.1 Form 1 – Cube:

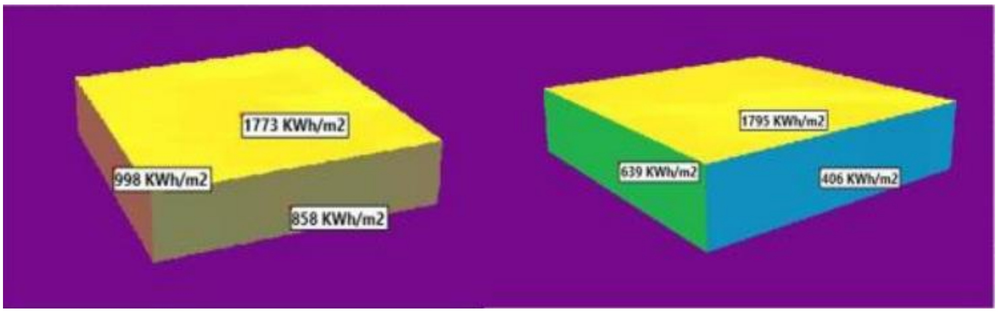


Figure 27: External radiation analysis

From the above analysis, we can infer that the maximum radiation is received through the roof (1795 KWh/m2). The West facade receives a maximum of 998KWh/m2 and the south receives 858KWh/m2.

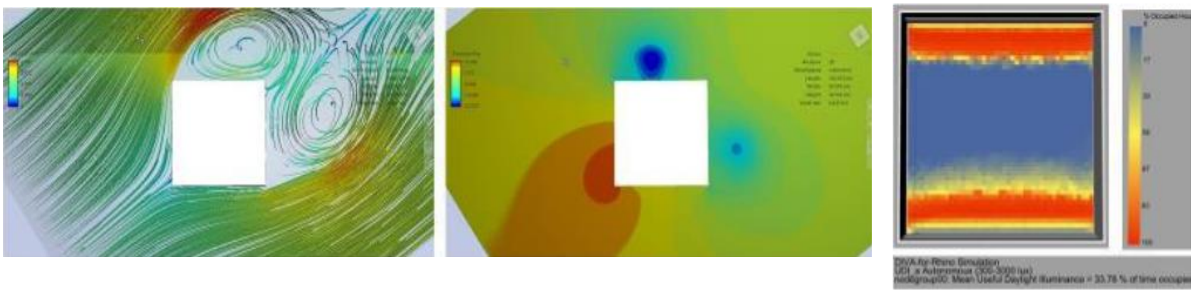
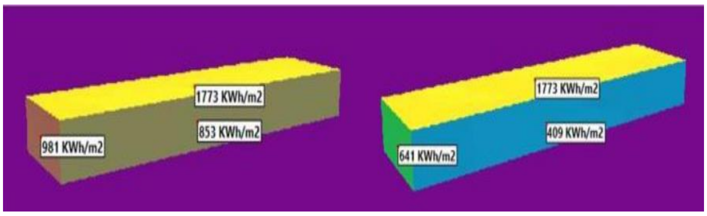


Figure 27: CFD analysis & Figure 28: Daylight analysis

The CFD analysis shows that the large Eddie current created on the North - East facade can result in discomfort in the building surrounding.

In figure 28, the daylight performance is observed by the UDI. The contour shows that 33% of the occupied hours receive daylight within the useful lux (300 - 2000).

4.1.2 Form 2 – Cuboid:



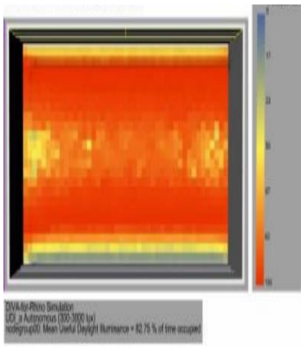


Figure 29: External radiation analysis (N-S oriented)
Figure 30: Daylight analysis

In Figure 29, we attempt to reduce the surface area of the west facade to minimize the total radiation but the south facade increases in area.
In Figure 30, the daylight performance is observed by the UDI. The contour shows that 82.75% of the occupied hours receive daylight within the useful lux (300 - 2000). Thus deeper plans have poor daylight performance.

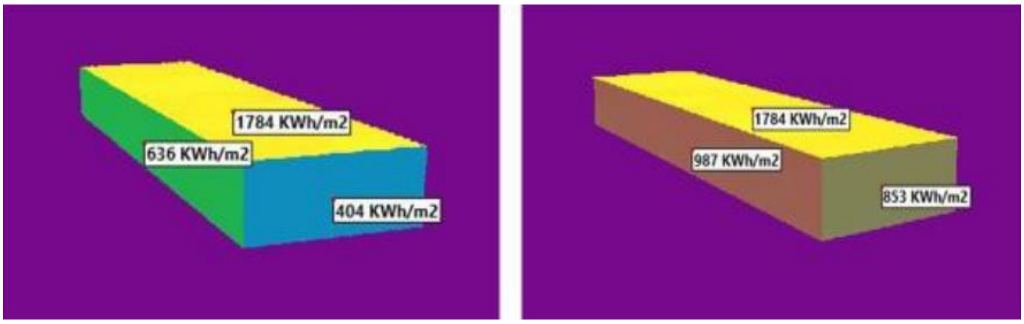


Figure 31: External Radiation analysis (E -W oriented)

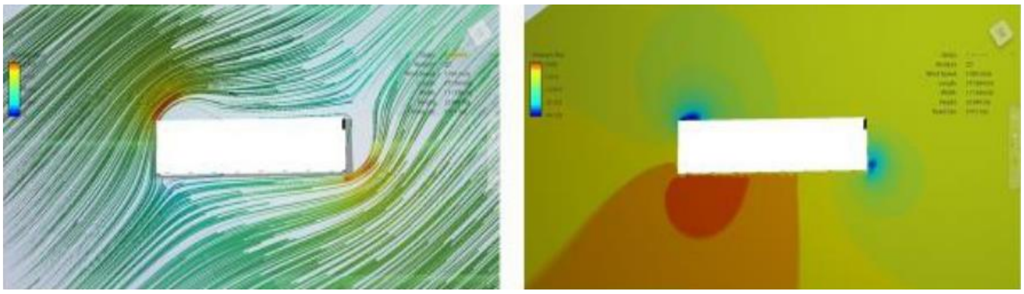


Figure 32: CFD analysis

In Figure 31, the form is used to develop the building mass further as the west facade surface area reduces and the south facade radiation can be reduced through envelope strategy.
In Figure 32, the CFD analysis shows that the form is aerodynamic, allowing the wind to flow freely through the site. It also allows a larger surface area towards the windward side.

4.1.3 Cuboid with courtyard:

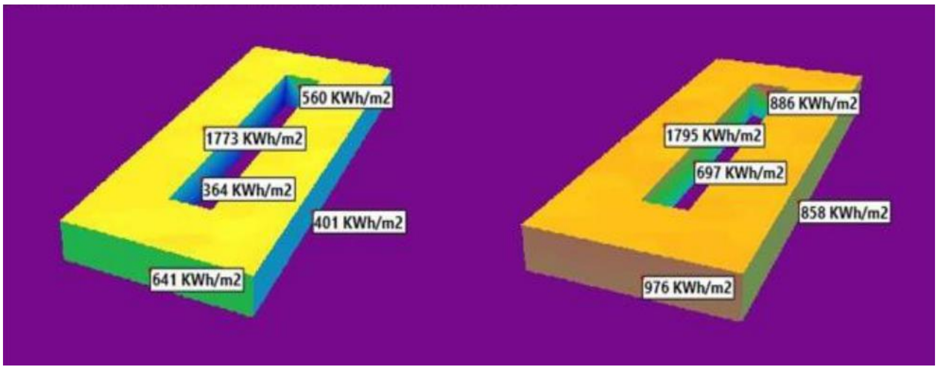


Figure 34: External radiation analysis (E - W orientation)

5. Concept and site plan

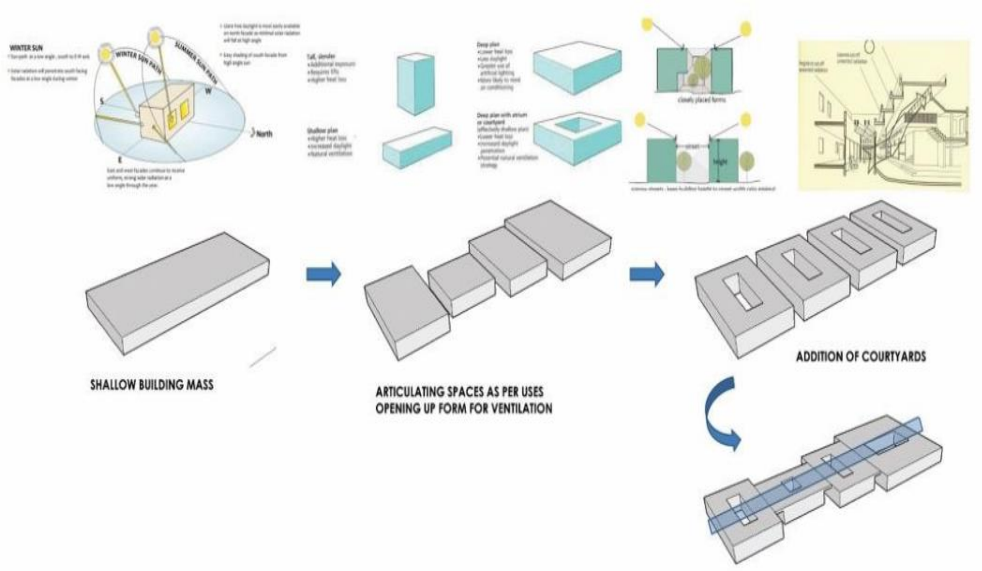


Figure 35: Concept

Figure 36: Site plan

6. Analysis and Result

6.1 Daylight analysis

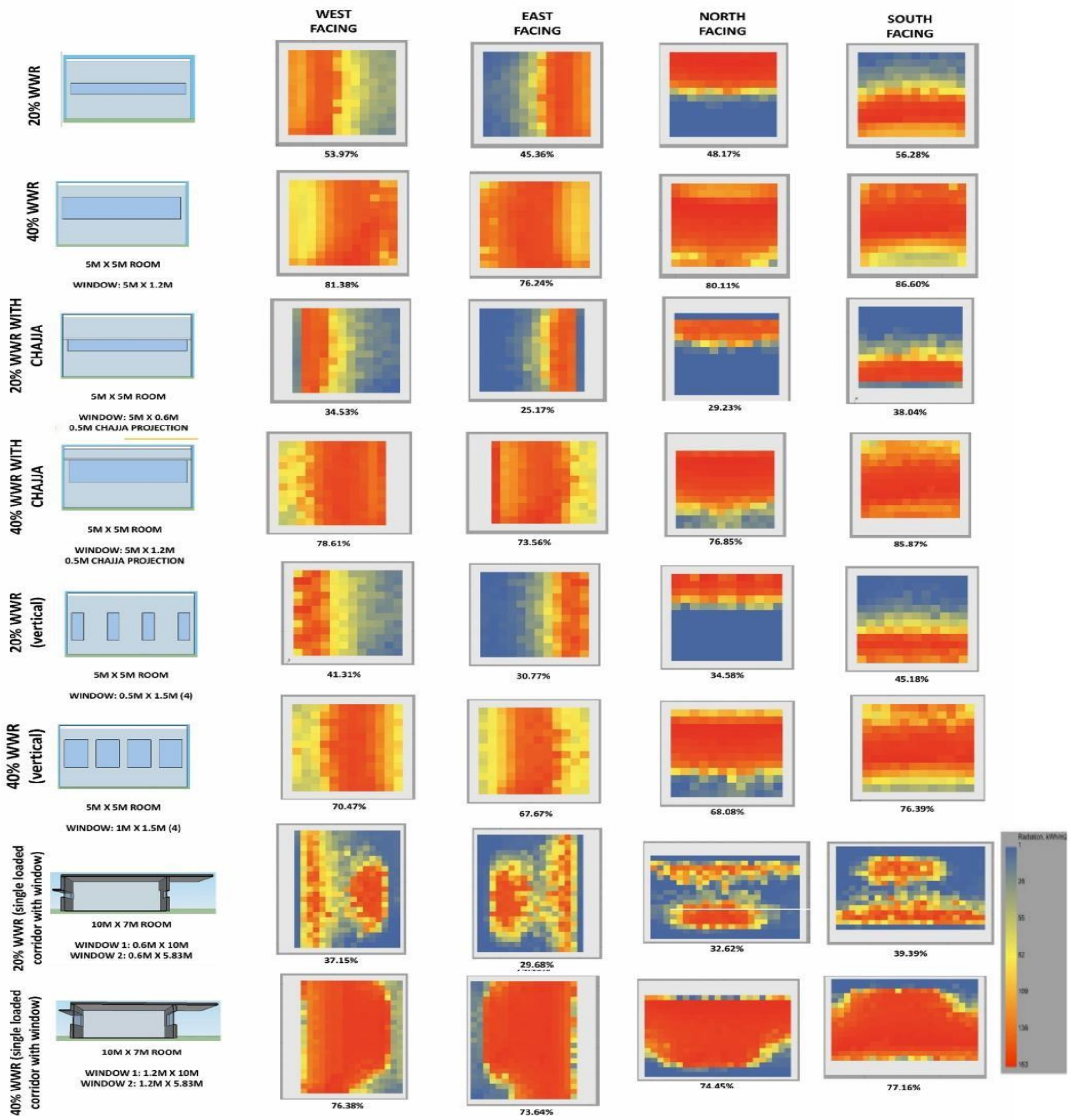


Figure 40: Daylight stimulation

WWR	*West*	*East*	*North*	*South*
40% WWR	*81.38%*	*76.24%*	*80.11%*	*86.60%*
40% WWR with chajja	*76.61%*	*73.56%*	*76.85%*	*85.87%*
40% WWR (single loaded corridor)	*76.38%*	*73.64%*	*74.45%*	*77.16%*
40% WWR (vertical)	*70.47%*	*67.67%*	*68.08%*	*76.39%*

Table 3: Optimum WWR in the order of performance in accordance to daylight

6.2 Internal radiation analysis

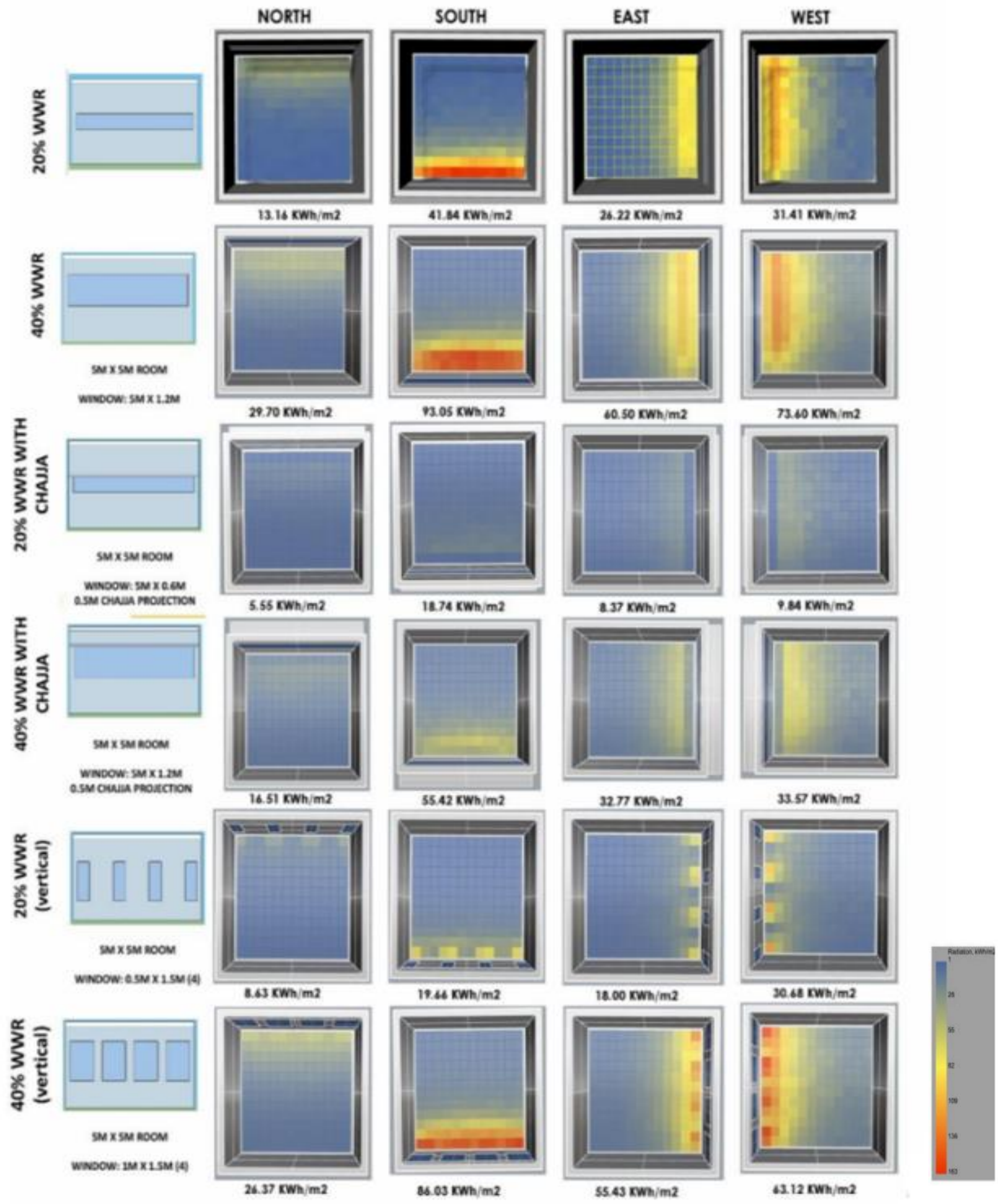
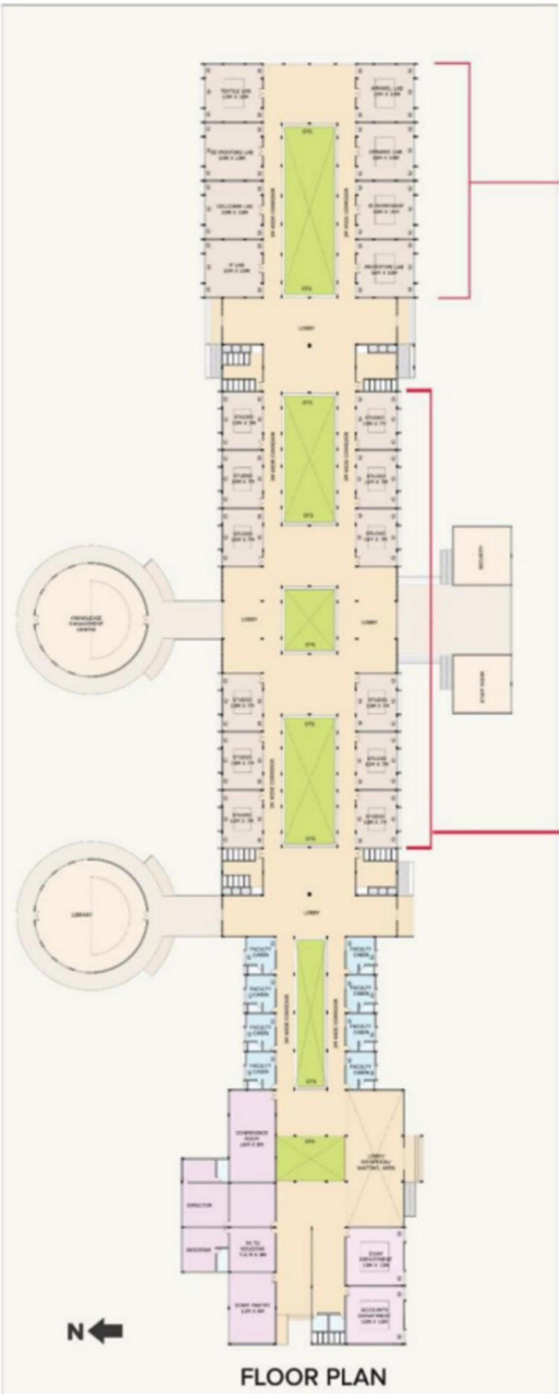


Figure 41: Internal Radiation Analysis

WWR	*North*	*South*	*East*	*West*
20% WWR with chajja	*5.55 KWh/m2*	*18.74 KWh/m2*	*8.37 KWh/m2*	*9.84 KWh/m2*
20% WWR (vertical)	*8.63 KWh/m2*	*19.66 KWh/m2*	*18.00 KWh/m2*	*30.68 KWh/m2*
40% WWR with chajja	*14.51 KWh/m2*	*55.42 KWh/m2*	*32.77 KWh/m2*	*33.57 KWh/m2*
20% WWR	*13.16 KWh/m2*	*41.84 KWh/m2*	*26.22 KWh/m2*	*31.41 KWh/m2*

Table 4: Optimum WWR in the order of performance in accordance to internal radiation

6.3 Design Analysis



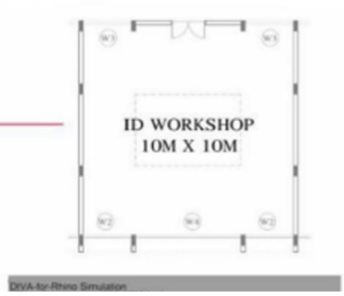


Figure 43: Workshop daylight stimulation

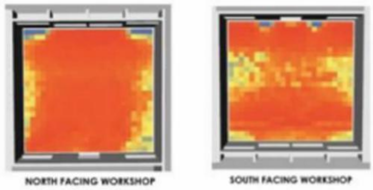


Figure 44: Studio daylight stimulation

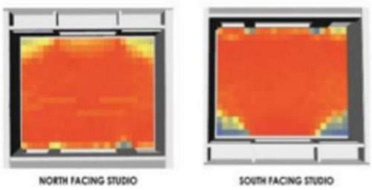


Figure 42: Plan

From figure 43, the percentage of space with a UDI (300 - 3000) larger than 50% is 100% for active occupant behaviour. From figure 44, the percentage of space with a UDI (300 - 3000) larger than 50% is 98% for active occupant behaviour.

Comparing daylight analysis and internal radiation analysis, a 40% window-wall ratio with chajja can be one of the best options for daylight in a building. The above analysis is for the region that is warm and humid. Similarly, the results vary depending on the region.

7. Conclusion

The above analysis proves that the North and the South axis are good for daylight without any glare in the space. Keeping in mind the amount of daylight in a room, 40% WWR is very good when located either in the North or the South. But the same can cause slight discomfort when it comes to internal radiation. Both the factors are inversely proportional, so it's best to consider both while designing.

The analysis also proves that the courtyard can play a key role in a building as far as daylight and radiation are concerned. The analysis of daylight stimulation and internal radiation level can give us the optimum orientation suitable for that particular region's climatic conditions.

Daylight is an important aspect in institutional buildings, it promotes psychological wellbeing and visual comfort as discussed before. Each space in an institutional building needs a different amount of daylight according to its functionality and users. Here, the most often used space is the studio and the user is the students. Students in universities/schools experience glare due to poor design of the building resulting in discomfort. This problem is felt but unrecognized.

In practice, this paper can act as a reference for designs that concentrate on daylight in warm and humid regions. Another area where this method can be used is to conserve a huge amount of energy during the day and also increase the energy efficiency of the building.

Acknowledgments

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