International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 08 Issue: 04 | April - 2024 SJIF Rating: 8.448 ISSN: 2582-3930

Enhancing Visual Comfort in Buildings through the Implementation of Anidolic Daylighting Systems

Tanisha Thakur [1], Ar. Yashika Garg [2]

[1] School of Architecture, IPS Academy, Indore
[2] School of Architecture, IPS Academy, Indore

---***---

Abstract - The integration of daylighting systems into building design has emerged as a critical aspect in creating visually comfortable indoor environments. This research paper explores the significance of daylighting strategies in enhancing visual comfort within buildings. Daylighting systems not only reduce energy consumption by substituting artificial lighting but also influence heating and cooling loads. Effective daylighting design encompasses various elements such as lighting quality, glare control, daylight utilization, visual ergonomics, aesthetic considerations, and adaptability. Through a comprehensive review of literature and case studies, this paper examines the principles, methods, and technologies employed in daylighting systems to optimize visual comfort for building occupants. Furthermore, the paper discusses the impact of geographical location, climate conditions, and architectural design on daylight availability and the effectiveness of daylighting strategies. The findings underscore the importance of holistic daylighting approaches in promoting occupant well-being, productivity, and satisfaction in indoor environments. By emphasizing the role of daylighting systems in achieving visual comfort, this research contributes to the advancement of sustainable and human-centric building design practices.

Key Words: Daylighting, visual comfort, Anidolic daylighting system, Anidolic ceilings, Anidolic Zenithal openings, Anidolic solar blinds

1.INTRODUCTION

1.1 Introduction to visual comfort

Visual comfort in building design aims to optimize indoor environments for occupants, enhancing productivity and well-being. Key elements include:

1) Lighting Quality: Ensuring appropriate light levels, color rendering, and flicker-free illumination to support tasks without causing visual strain.
2) Glare Control: Employing shading, diffusing surfaces, and adjustable fixtures to mitigate glare, enhancing visual perception and comfort.
3) Daylight Integration: Strategically placing windows and skylights to utilize natural light while minimizing glare and solar heat gain.
4) Visual Ergonomics: Considering human visual capabilities and preferences to create comfortable viewing conditions.
5) Aesthetic Considerations: Utilizing color schemes, materials, and textures to promote visual comfort and perception of comfort.
6) Adaptability and Control: Providing occupants with means to adjust lighting levels and glare according to their preferences through dimmable lighting and user-friendly controls.

1.2 Introduction to Daylighting

Daylighting is a design strategy that aims to utilize natural light to illuminate the interior space of buildings. It goes beyond mere illumination and encompasses achieving visual comfort, enhancing architectural aesthetics, and reducing energy consumption. The strategic placement of windows, skylights, and other openings allows for the penetration of natural light, creating a dynamic and visually engaging environment. The interplay of light and shadows brings a sense of warmth and vitality to interior spaces, positively impacting occupants' well-being and productivity.

When well-implemented, daylighting systems can create a harmonious connection between indoor and outdoor environments, fostering a sense of openness and connectivity. The careful consideration of factors such as glare control, daylight distribution, and solar heat gain leads to a balanced and comfortable visual environment, enhancing the overall quality of the built environment.

1.3Principles of Daylighting

The integration of daylighting strategies and architectural design is imperative from the inception of building design, as they are inherently intertwined.

Daylight serves not only as a substitute for artificial lighting, reducing energy consumption, but also impacts heating and cooling loads.

Planning for daylight necessitates collaboration among various disciplines and professionals to incorporate diverse perspectives and requirements.

Daylight strategies are contingent upon natural light availability, determined by factors like the building's latitude and immediate surroundings such as obstructions.

Climate plays a crucial role in daylighting strategies, necessitating identification of seasonal variations, prevailing climate conditions, and sunshine probability.

Understanding the climate and daylight availability at each façade is fundamental for effective daylight-centric design.

In high latitudes with distinct summer and winter conditions, maximizing daylight penetration during low daylight periods, such as winter, is often the goal.

Redirecting daylight from the brightest sky regions is a viable strategy for enhancing daylight levels in buildings at higher latitudes.

Conversely, in tropical regions with consistently high daylight levels, the focus shifts to preventing overheating by limiting daylight ingress.

This can involve obstructing large portions of the sky, particularly near the zenith, and allowing daylight only from lower sky areas, or indirectly utilizing ground-reflected light.

2. DAYLIGHTING SYSTEMS

2.1 Introduction to Daylighting Systems

Daylighting systems harness natural light for illumination, minimizing glare and heat. They enhance ambiance, reduce energy usage, and promote wellbeing and productivity. Innovative solutions like light shelves and automated shading ensure seamless integration, fostering harmony with the environment.

2.2 Benefits of using daylighting systems

- Energy saving Daylighting systems lead to reduced electricity usage, increasing the building's energy efficiency and sustainability.
- Enhanced comfort- Natural light decreases visual fatigue, enhances the perception of indoor spaces, and positively impacts occupant satisfaction.
- Biophilic connection- Access to natural light fosters a connection to the outdoors, promoting a sense of comfort, creativity, and well-being among occupants.

2.3 The key parameters to consider in choosing a system are

- Site daylighting conditions—latitude, cloudiness, obstructions
- Daylighting objectives
- Daylighting strategies implied in the architectural design
- Window scheme and function
- Energy and peak power reduction objectives
- Operational constraints -fixed/operable, maintenance considerations
- Integration constraints —architectural/construction integration
- Economic constraints
- Achieving solar shading, thermal control.

3. TYPES OF DAYLIGHTING SYSTEMS

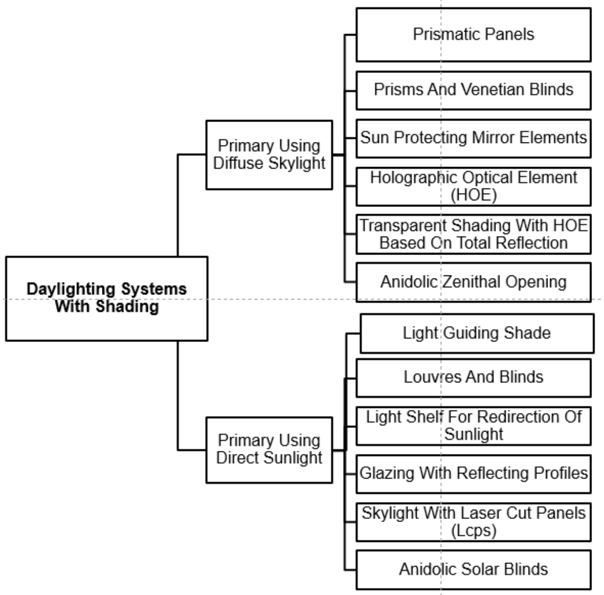
3.1 Daylighting Systems with Shading

Two categories of daylighting systems incorporating shading are discussed:

1. Type relies predominantly on diffused skylight, filtering out direct sunlight,
2. Utilizes direct sunlight, directing it onto ceilings or areas above eye level

These shading systems serve dual purposes, providing solar shading and facilitating daylighting, often addressing additional concerns like glare mitigation and redirection of both direct and diffused light.

Conventional solar shading methods, like pull-down shades, frequently diminish the entry of daylight into a space. To optimize daylighting while offering shading, more advanced systems have emerged, shielding the vicinity around windows from direct sunlight while channeling both direct and diffused daylight into the room's interior.



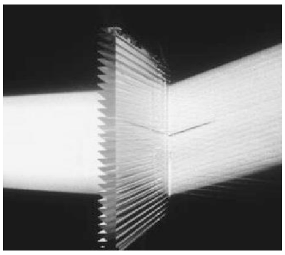


Figure. Prismatic Panels


Figure. Glazing


Figure. Prisms And Venetian Blinds


Figure. Louvres And Blinds

Figure. Skylight With Laser Cut Panels (Lcps)

Figure. Glazing With Reflecting Profiles

3.2 Daylighting Systems Without Shading

Daylighting systems devoid of shading are primarily engineered to redirect daylight away from window or skylight openings. Their function may or may not involve the obstruction of direct sunlight. These systems can be categorized into four distinct types:

1. Diffuse Light-Guiding Systems
2. Direct Light-Guiding Systems
3. Light-Scattering or Diffusing Systems
4. Light Transport Sys

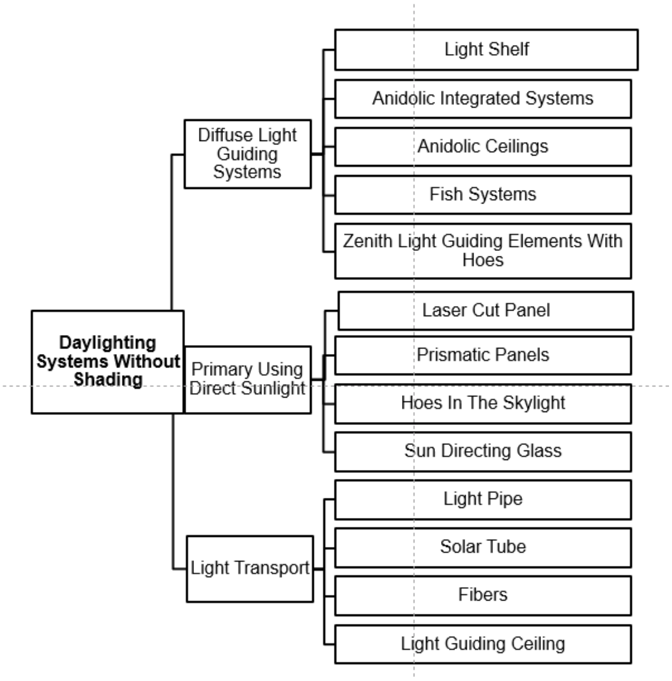


Figure. Light Shelf

Figure. Fibers

Figure. Solar Tube

Figure. Light Pipe

4. ANIDOLIC DAYLIGHTING SYSTEMS

This system is one of the most effective daylighting systems available; it directs natural light rays to various deep parts of the house and building. It employs the principles of using minimum reflection and non-imaging optics. Non-imaging optics is a light collector that distributes it efficiently and evenly throughout the building without the help of any artificial lighting systems. The three different systems which are anidolic ceiling, an integrated anidolic system, anidolic zenithal openings, and anidolic solar blinds they have all different results but still aim at one thing, being able to improve visual comfort and increase illuminance levels.

This system captures a light guide to collect sunlight and direct it to rooms without the risk of direct sunlight into the eyes. In this result, it makes the room ten times brighter compared to sunlight that is direct in the room. Anidolic mirror lighting systems have three different parts, to capture daylight, it uses an anidolic zenithal collector. The optimal passageway of light is through an anidolic ceiling and the distribution of light to different areas of the room. The anidolic ceiling uses a light duct that guides daylight flux in the room space.

4.1 Non-imaging optics principles

The characteristics of anidolic systems, as outlined by Scartezzini and Courret (2002), include:

- Rooted in non-imaging optics principles, particularly the Edge-Rays principles.
- Minimization of light reflections by maximizing the collection and distribution of daylight flux, in accordance with the Law of Conservation of Etendue.
- Precise definition of the admittance sector for incoming light rays, enabling the capture of diffuse daylight from the sky vault.
- Exhibiting high angular selectivity for exiting light rays, acting as a "Beam Projector" for diffuse daylight.

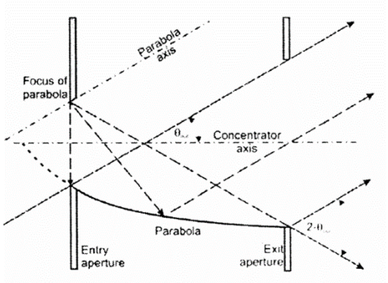


Figure. the basic principles of compound parabolic concentrator (CPC) based on edge-rays principles scartezzini and courret (2002)

4.2 Types of Anidolic Daylighting Systems

4.2.1Anidolic ceilings

Anidolic ceiling systems leverage compound parabolic concentrators to gather diffuse daylight from the sky. These concentrators are linked to a specular light duct above the ceiling plane, directing the light to the rear of a room. The main goal is to ensure sufficient daylighting in rooms, particularly during overcast sky conditions.

Technical description:

An anidolic ceiling comprises daylight-collecting optics linked to a suspended ceiling light duct, primarily intended for illuminating nonresidential buildings from the side. Anidolic (non-imaging) optical elements are positioned at both ends of the light duct. Outside the building, an anidolic optical concentrator captures and concentrates diffuse light from the upper sky vault, typically the brightest area during overcast conditions, efficiently channeling rays into the duct. A parabolic reflector at the duct's exit aperture in the rear of the room evenly distributes the light downward, preventing back reflection. Multiple specular reflectors within the light duct, covering most of the area above the ceiling, further transport daylight deeper into the room. To manage direct sunlight on sunny days, a blind can be deployed over the entrance glazing.

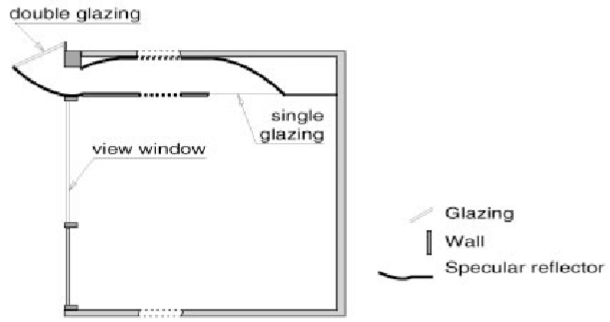


Figure. illustrates the entire anidolic ceiling system schematically.

Physical Principles and Characteristics:

The field of non-imaging optics has developed dependable and efficient methods for designing solar concentrators, nearly reaching the theoretical limit of solar concentration as per the law of thermodynamics (Welford and Winston, 1989). These optical principles can also be applied to devise systems that optimize the utilization of diffuse light from the sky vault. Key features of such systems include:

- Ensuring that the "bundle size" of light rays defined by specific angles at the entry aperture is fully transmitted at the exit aperture, covering all hemispherical directions.
- Minimizing the number of reflections through careful design to achieve high optical efficiency.
- Achieving precise selection of incoming rays at the entry aperture and control of emerging rays at the exit aperture, facilitated by high angular selectivity.

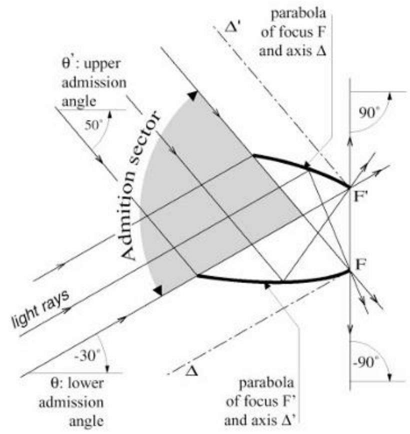


Figure. Principles of 2-D, non- symmetric anidolic system

The anidolic ceiling system was developed based on these principles, incorporating:

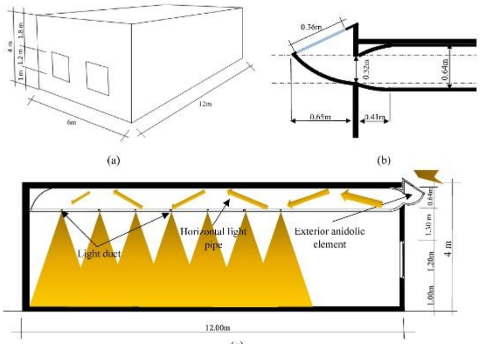
- An anidolic daylight collector placed in front of the light guide to collect and concentrate daylight at the duct's entrance.
- Another anidolic device installed at the duct's end to evenly distribute daylight flux into the roFom, avoiding visual discomfort.

While the system primarily relies on sky illumination, achieving light concentration is crucial for its performance. Despite a concentration factor of 2 to 3 under overcast skies, this is sufficient to meet desired interior daylight illuminance levels. At the interior end of the duct, a second anidolic device "deconcentrates" light to direct the flux toward the work plane.

Application:

The system is most suitable for vertical facades in buildings situated in areas with predominantly overcast conditions and limited access to direct sunlight or facing obstructions across a significant portion of the sky vault. Design considerations include:

- Efficient collection of available daylight from the sky vault, even during unfavorable overcast conditions, such as winter.
- Reduction of glare risks by directing daylight from the facade into the room and redistributing it downward from the ceiling in a conventional manner, akin to electric lighting.
- Compatibility of light duct dimensions with available building space.



Channeling light in a duct above the ceiling diminishes the likelihood of unwanted glare. When direct sunlight is the primary source, a high concentration factor allows for a smaller duct system, occupying less of the ceiling plenum. However, in applications focused on providing daylighting under overcast conditions with the sky as a diffuse source, concentration is limited to a factor of 2 or 3, necessitating a larger light duct. The present design has been optimized accordingly to accommodate a light duct filling the entire ceiling plenum cavity.

Anidolic ceilings are versatile and applicable in densely populated urban areas as well as rural settings. Their impact is particularly notable in urban environments where obstructions surrounding buildings emphasize the importance of capturing diffuse light from the upper sky vault. These ceilings can function effectively in both clear and cloudy skies with appropriate shading to control sunlight.

Commercial, industrial, or institutional buildings can benefit from anidolic ceilings. Design solutions will vary based on climate and latitude. Renovation projects involving buildings with deep ceiling plenum spaces or high ceilings may find an application if significant obstructions are absent, and there's no interference with other building systems.


Figure. LESO Solar Experimental Building, Switzerland

4.2.2 Anidolic Zenithal Openings

The anidolic zenithal opening represents a daylighting solution rooted in non-imaging optics. Leveraging its high angular selectivity, this device efficiently gathers diffuse daylight from a significant portion of the sky vault while preventing direct sunlight penetration. Ideal for single-storey buildings, atrium spaces, or upper floors in multi-storey structures, this sky lighting system optimally delivers daylight into interior spaces.

Technical description:

The anidolic zenithal opening system comprises an optical concentrator and a "deconcentrating" or emitting element. The collector utilizes a linear, two-dimensional, non-imaging compound parabolic concentrator oriented along the east-west axis. The opening is tilted northward in the northern hemisphere to ensure that the admitted light sector encompasses the entire sky from the northern horizon to the highest position of the sun in the southern sky throughout the year. Solar protection is achieved through a series of vertically aligned slats uniformly distributed over the aperture at 0.5-meter intervals


Figure. Showing anidolic zenithal opening

The admission angle, denoted as q, measures 50°, while the tilt angle, represented by a, is set at 40° from the horizontal. These angles are calculated using a straightforward equation outlined in Courret [1999] and are contingent on the site's latitude, which stands at 47°N in this instance. Positioned at the emitting end of the opening, a compound parabolic deconcentrator, similar in design to the previously mentioned compound parabolic concentrator but reversed, directs the daylight flux towards the bottom of the room. The exit angle of the device, denoted as qd, measures 40° and is truncated at 45° to reduce its length. Under typical circumstances, the anidolic zenithal opening does not act as a direct glare source for building occupants.

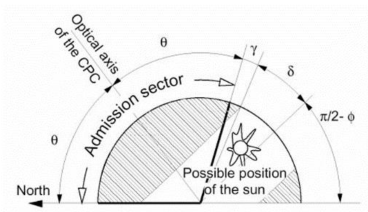


Figure. Admission sector of and anidolic zenithal opening

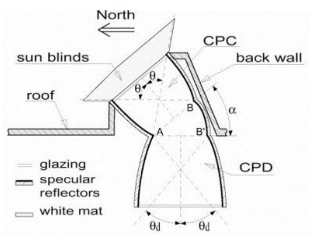


Figure. Cross section of an anidolic zenithal opening

Application:

The anidolic zenithal opening is specifically engineered for rooftop installations. Positioned to face north in the northern hemisphere, this design offers a distinct advantage: it provides consistent daylight levels that are less susceptible to fluctuations caused by cloud movements or changes in the sun's position. Compared to systems admitting direct sunlight, this results in more stable luminous output, reducing glare and enhancing visual comfort. As a result, this design is particularly well-suited for indoor spaces where optimal visual comfort is crucial, such as sport halls, museums, atria, and markets.

International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 08 Issue: 04 | April - 2024 SJIF Rating: 8.448 ISSN: 2582-3930

However, it may necessitate larger aperture areas than systems designed for direct sunlight admission.

4.2.3 Anidolic Solar Blinds

Anidolic solar blinds comprise a grid of hollow reflective elements, each composed of two three-dimensional compound parabolic concentrators. These blinds are engineered for side lighting, offering angular-selective light transmission to manage sunlight and glare. Currently, the design is in the prototype and demonstration phase.

Technical description:

The distinguishing feature of anidolic solar blinds, in contrast to other anidolic systems like anidolic ceilings or zenithal openings, lies in their utilization of three-dimensional reflective elements and their compact size. These blinds are specifically engineered to optimize their optical properties. The admitting portion of the blinds is designed to selectively reject high-solar-altitude rays from direct sunlight while permitting the transmission of lower altitude diffuse light or winter sunlight. The fraction of rejected rays as depicted, varying with altitude and azimuth. The design of the admitting portion can be customized to suit the facade orientation and typical daily temperature cycles, ensuring adequate solar penetration as needed throughout the day. On the other hand, the emitting portion of the blinds is engineered to direct daylight into the upper quadrant of the room, towards the ceiling, and to disperse the light horizontally within a range of ±25° from the window surface normal. This design effectively diffuses transmitted sunlight without causing glare.

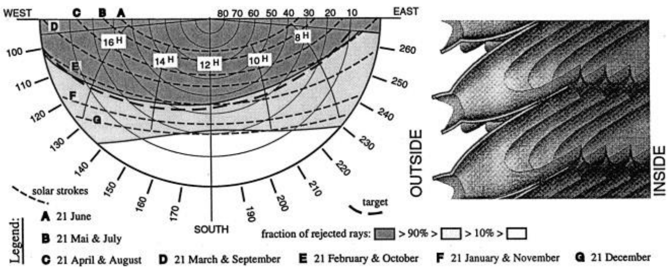


Figure. Section of 3-D model of anidolic solar blinds

Physical Principles and Characteristics:

The system design, based on non-imaging optics, resembles other anidolic systems but utilizes three-dimensional elements. Experimental findings, indicate that the anidolic solar blind system achieves a maximum transmittance of 26% in the central part of the admitting zone. This value corresponds to the ratio of the effective areas of the apertures for the most favorable angles of incidence. Any deviation between theoretical and measured angular selectivity primarily stems from the production process of the prototype.

Application:

Anidolic blinds are a fixed system to control daylight and thermal gains in south-facing or other facades that receive extensive sunlight. The blinds are intended to increase daylight penetration under a wide range of conditions while preventing the interior space from overheating. They do not use any moving parts. Although the system is mainly designed to control daylight in sunny climates, it may be used under predominantly cloudy skies

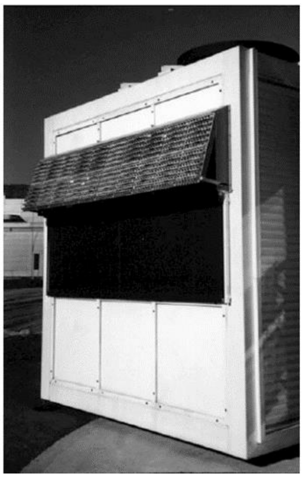


Figure. Anidolic solar blinds

4.2.4 Integrated Anidolic Systems

An Integrated Anidolic System embodies a holistic approach that incorporates anidolic principles into diverse facets of building design, aiming to elevate both daylighting efficiency and energy conservation. By integrating optical elements like light collectors and reflective surfaces seamlessly into architectural structures, this system optimizes the capture and dispersion of natural light.

This sophisticated system employs cutting-edge optical technology to enhance daylight penetration while mitigating issues such as glare and heat accumulation. Its components, including anidolic ceilings, light shelves, and tubes, are strategically positioned within the building layout to orchestrate an optimal distribution of sunlight.

Engineered to harmonize with architectural elements, the Integrated Anidolic System leverages reflective surfaces to channel sunlight into interior spaces, ensuring uniform illumination throughout the building. Through adept utilization of natural light, it curtails reliance on artificial lighting, leading to substantial energy savings and heightened comfort for occupants.

Technical description or Key Components:

- Anidolic Daylight Collector: The system begins with an anidolic daylight collector positioned on the exterior of the building. This collector comprises non-imaging optical elements, such as compound parabolic concentrators (CPCs), designed to capture and concentrate diffuse daylight from the upper hemisphere of the sky vault. The collector efficiently redirects incoming light rays towards the building's interior.

- Light Duct: Once captured, the concentrated daylight is directed into a light duct integrated into the building's structure. The light duct serves as a channel for transporting daylight from the exterior collector to the interior spaces of the building.
- Anidolic Distribution Device: At the end of the light duct, an anidolic distribution device is employed to evenly distribute the daylight flux throughout the interior space. This device ensures uniform illumination while minimizing visual discomfort and glare.
- Control Mechanisms
- Reflective Surfaces: Reflective surfaces, such as specular reflectors or mirrors, may be strategically positioned within the light duct to enhance light transmission and minimize losses due to absorption or scattering.

Application:

- Daylight Optimization
- Solar Energy Utilization
- Passive Solar Climate Control
- Seamless Architectural Integration

Figure. Showing integrated anidolic system

CONCLUSION

In summary, this thorough investigation emphasizes the vital role of daylighting systems in enhancing visual comfort, energy efficiency, and environmental responsibility in buildings. By integrating diverse daylighting techniques, principles, and technologies, the study demonstrates their benefits for occupant well-being and productivity. Collaboration across professional fields is essential for incorporating daylighting strategies into architectural designs from the project's outset.

The examination of various daylighting systems, categorized into shaded and unshaded approaches, offers valuable insights for designers and architects. From diffused skylights to innovative anidolic systems, each presents advantages in optimizing daylighting while addressing glare and light redirection concerns, especially in urban environments. Anidolic systems efficiently capture and distribute natural light, enhancing visual comfort and energy efficiency while minimizing glare and overheating risks. Overall, this research advances sustainable building design by highlighting the importance of daylighting systems. Through innovative strategies, designers can prioritize occupant well-being and environmental sustainability, shaping the future of architectural design to meet diverse needs and challenges.

REFERENCES

1. Anidolic daylighting system: a sustainable daylighting technology for high rise and high-density residential buildings
2. Daylight in buildings and visual comfort evaluation: the advantages and limitations amir tabadkani,∗,a astrid roetzel,a hong xian li,a aris tsangrassoulisb
3. https://doi.org/10.3390/su10010071
4. https://doi.org/10.1016/0927-0248(93)90088-k
5. Din-5034-1, daylight in interiors deutsches institute fur normung e.v. (din), 2011, p. 17.
6. Architecture and daylight: planning strategies for energy - efficient buildings in india alpana kamble1, dr. Ila gupta2
7. An empirical study of visual comfort in office buildings
8. The effects of lighting conditions on visual comfort, satisfaction and motivation levels of architecture students, by merve durgut
9. Indoor visual comfort: a review of factors and assessments pankaj dhayal1* & dr. Bandana jha2
10. Mohamed boubekri (2008) daylighting, architecture and health building design strategies. Elsevier,2008th edn. Moscoso, c. & matusiak, b. (2
11. Determining proper daylighting design solution for visual comfort and lighting energy efficiency: a case study for high-rise residential building z a kiliç1 and a köknel yener2
12. Reinhart c f 2014 daylighting handbook i (boston:massachusetts institute of technology)
13. Analysis of anidolic daylighting system parameters in tropical climate mohsen roshan*2,3, mohd zin kandar1, hamed najafpour2, dilshan r. Ossen2, mohsen ghasemi2, alireza gharakhani2, mahdi torabi2
14. Anidolic daylighting systems †,‡ jean-louis scartezzini and gilles courret §
15. Effects of ceiling characteristic of anidolic lighting system on daylighting in office buildings in thailand bormey long1* and nuanwan tuaycharoen1