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Facade Design Strategies to utilize Daylight in Composite Climate

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***Abstract:** An overview of the building envelopes and shading techniques utilised in composite climates to make advantage of solar radiation and daylight in modern architecture is provided in this study. It provides an examination of various methodologies and a concise analysis of illustrative case studies. As it has an impact on a building's energy usage, daylighting plays a significant part in sustainable architecture. By encouraging excellent human health, well-being, and user comfort, daylight not only lessens the need on artificial lighting but also serves to increase job productivity. This paper involves both passive strategies as well as adaptive facades that can be used in composite climate. Due to their capacity to alter their behaviour in real time in response to interior and outdoor conditions through the use of materials, components, and systems, adaptive building envelopes can enhance a building's energy efficiency and economics. Several various kinds of adaptable facades have already been created, and more cutting-edge developments are likely to follow soon. Various strategies and literature studies already existing are discussed in this paper.*
***Keywords:** Building Facades, Building Skins, Composite Climate, Daylight, Passive Strategies, Adaptive Facades*

I. INTRODUCTION

In a world exposed to climate change, there is an urgent need to build an envelope that responds optimally to the climate and provides maximum comfort and indoor environmental quality while maintaining high efficiency. Building design has become a difficult task as it must meet increasingly ambitious environmental, social and economic performance requirements. Every day and every year, the weather changes. This also holds true for the needs related to comfort and occupancy. The design of low energy buildings has evolved in two ways during the past few decades - Active technology and passive design methods. The first methods strive to improve the built environment's sustainability by introducing cutting-edge technical innovations. These devices are utilised for the decentralized production and provision of energy from renewable energy sources, as well as for the more efficient conversion of resources. On the other hand, the "passive" refers to buildings where the structure and shape of the building itself play an important role in the acquisition, storage and distribution of wind and solar energy, as opposed to building maintenance. Using building skins that combine the beneficial characteristics of active and passive building technologies, climate-adaptive building skins can exploit the concepts of adaptation, multi-functional, and evolution. Facades should respond appropriately in order to maintain or improve the functional needs of the envelopes in terms of air, heat and water vapour movement, solar radiation, rain penetration and aesthetics.

The design of the majority of the building skins are centred on providing protection and shelter. This is frequently achieved by making the interior environment largely unaffected by the environment. The unfortunate result is the installation of critical mechanical and electrical systems to provide ventilation, air conditioning, lighting, and heating to meet satisfaction demands at the cost of energy consumption and other natural resource usage. Three stakeholders affect the design of facades involving environment, user, owner. Environmental deterioration is the major problem we will be dealing with in the present and the future. It is feasible to minimise the environmental effect by continuously optimising the use of resources, space, and energy with a holistic perspective. The architecture of a workplace has a significant influence on the health, happiness, and productivity of its workers. This approach aims to promote structures that maximise advantages for individuals by offering them high levels of comfort, which enhance their wellness and productivity. Ensuring enough lighting, noise levels, natural ventilation, etc. will improve their health and wellness, and offering high-quality environments will assist them in improving their work-life balance. Reduced operating costs, increased occupant comfort, and other associated advantages will all be felt as a result of these developments. A sustainable office building delivers realistic solutions that are economically viable to execute and will enable business benefits due to a lower lifespan cost, in addition to enhancing environmental performance and meeting tenant expectations.

Fig. 1, Evolution of facades over time

II. UNDERSTANDING BUILT ENVIRONMENT IN COMPOSITE CLIMATE

Large land masses around the tropics of Cancer and Capricorn typically have this climate because they are sufficiently far from the Equator to undergo dramatic seasonal fluctuations in solar radiation and wind speed. Lucknow, Noida, Kanpur, Chandigarh and New Delhi are a few examples of cities in India with this climate. Two-thirds of the year is hot and dry and the other one- third is warm and humid.

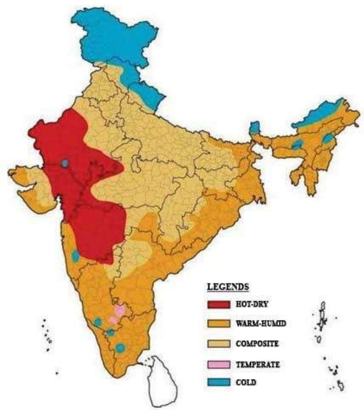

Fig. 2, Climatic Zones of India

Natural illumination in composite climates varies widely because of cloudy and clear sky circumstances. Controlling the day light is necessary to offer optimum illumination in the winter and minimal illumination in the summer. For this use, shading devices are ideal. With regard to solar radiation, daylight, and wind, orientation is a crucial design element in solar passive design. The summer months bring the most sun radiation to the East and West. Winter months are when south orientation receives the most solar radiation. Due to the great intensity of solar radiation that is received throughout the summer, when internal gains are also at their height, west is a critical direction. Designers must thus use extreme caution while creating the areas behind and around the West facade. Glare can result from direct sunlight. By incorporating shade components with windows, it may reduce glaring daylight contrasts, block unpleasant direct sunlight, and keep out the heat from the sun. Therefore, shading mechanisms are required to provide glare-free natural light. Shading tools are essential for reducing mechanical cooling demands as well as for aesthetic and thermal comfort. Openings like windows must be shaded, and the Window-Wall-Ratio (WWR) should not exceed more than 60%. With a significantly lower WWR, effective day lighting is possible.

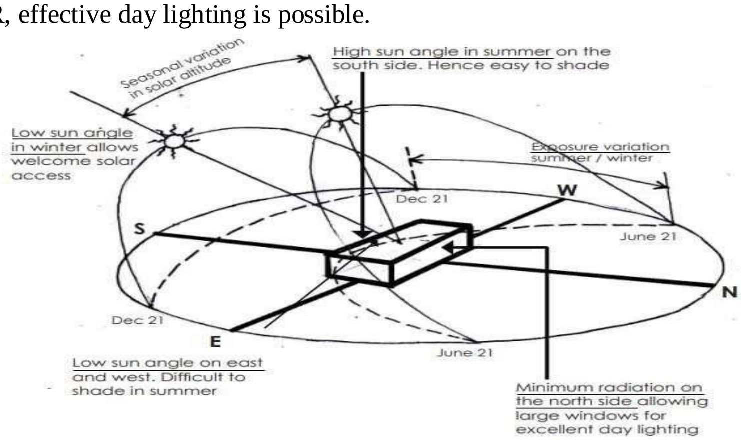

Fig. 3, Building Orientation in Composite Climate

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III. LITERATURE SURVEY

Three parameters are considered in this paper for the study of facades involving- Material, Components, Facade system.

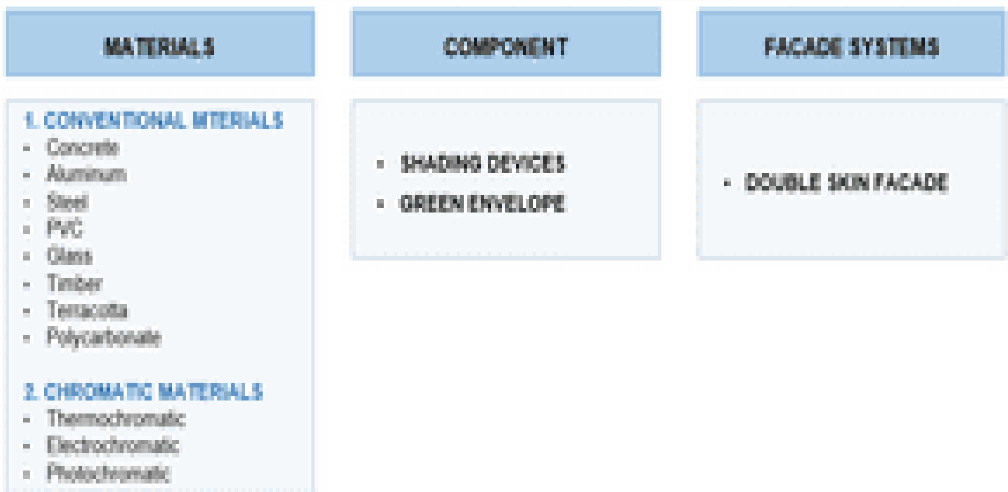

Fig. 4, Parameters considered for the study of Facades

A. Materials

- *Conventional Materials*

MATERIAL	SPECIFIC HEAT CAPACITY (J/Kg.K)	THERMAL CONDUCTIVITY (W/m.K)	DENSITY (KG/m³)	'U' VALUE (W/m².K)
CONCRETE	1000	1.13	2000	0.18 TO 0.99
ALUMINIUM	896	250	2700	5.34 TO 5.65
STEEL	480	45	7800	0.65 TO 1.2
POLYCARBONATE	1200	0.19-0.22	1200	0.9 TO 0.56
PVC	900	0.14-0.28	1350	1.13 TO 1.19
GLASS	840	0.8	2200	0.7 TO 1.22
TIMBER	1200	0.14	650	0.5 TO 0.64
TERRACOTTA	900	0.31	1700	0.08

- *Chromatic Materials*

These technologies are directly incorporated into the glass rather than being internal or exterior to the building. The degree of voltage and power can alter their physical characteristics, changing the glazing's optical property and increasing or decreasing its transparency.

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1) Thermochromatic Materials

Materials that are thermochromic exhibit a significant change in optical properties as a function of temperature, such as when heated. Thermochromic materials undergo a phase transition or a chemical reaction that is caused by heat to change their colour. They undergo a physical phase transition that drastically alters their properties and results in light scattering or multiple absorption. These materials can be used to regulate a glazing's or a building's skin's transmittance and infrared emissivity. They must be changed to switch in the human comfort range for glazing application.

When the temperature increases, thermotropic polymers immediately transition from a clear to a substantially scattering state. They are therefore appropriate for use as light guides and in sun, glare, and overheating protection applications. The energy needs of buildings are reduced by these materials.

Clear State

Tinted State

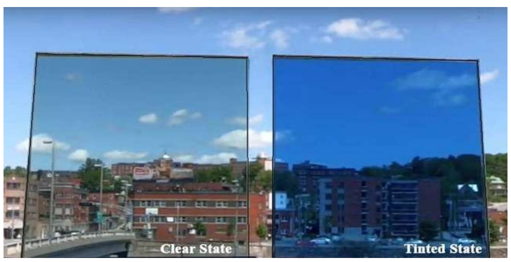
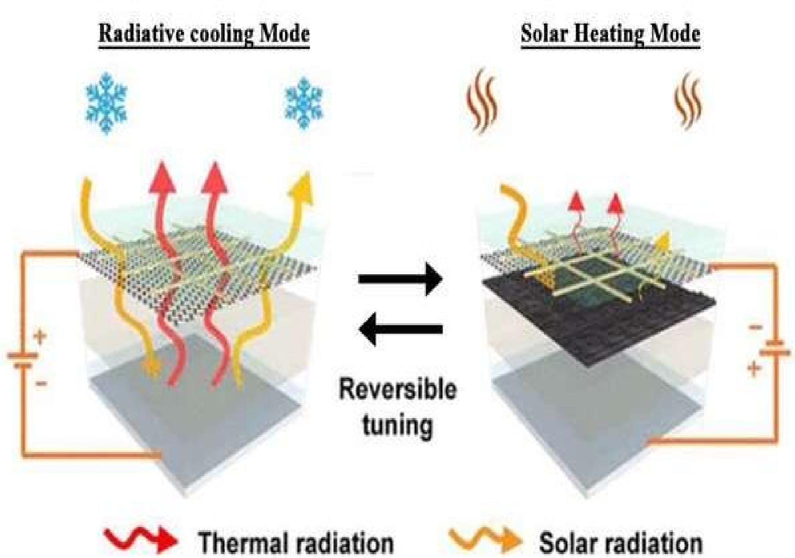


Fig. 5, Thermochromic glazing

2) Electrochromatic Materials

Dispersed liquid crystal, suspended particles, and electrochromic make up the electrically activated chromogenic. When electrochromic materials are exposed to a weak electric field, they can change their transparency and the colour with respect to the solar radiation in a reversible way. The electrochromic materials, which are created in the form of thin layers, are frequently incorporated into a panel of laminating or insulating glass for the smart windows or switchable windows.. It can alter how transparent it is to sun rays. Both visible and infrared sun energy can be transmitted in a variety of ways thanks to them.



The material takes approximately two minutes to transition between states

Fig. 6, Electrochromic glazing

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3) Photochromatic Materials

Photochromatic material performs the same function as Electrochromatic materials but without any electric charge. Numerous organic and inorganic materials exhibit photochromism. There are two categories of photochromic materials for glazing's. Metal halide-based photochromic glass and photochromic polymers are also available. Other kinds of photochromic, such photochromic insulating aerogels, exist but have not yet been investigated for glazing. When exposed to UV radiation from the sun, photochromic materials alter their optical characteristics, which they return to in the dark. Photochromic materials often absorb energy. The phenomenon essentially involves the reversible transition of a single chemical species between two energy levels with distinct absorbance spectra. Electromagnetic radiation has the ability to cause this shift in states (usually UV light).

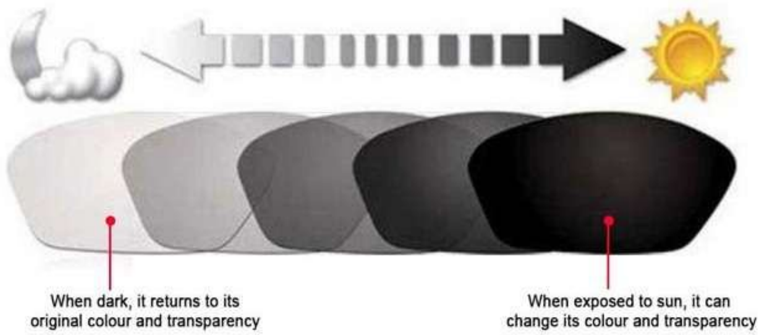

Fig. 7, Photochromic glazing

B. Component

A variety of shading arrangements, including permanent, manual and automated moveable, internal and exterior shading devices, have been developed in response to these potential advantages. The orientation of the building must be considered in the solar shading system's design. All sides can employ the interior systems and solar control glazing.

1) Passive Shading Devices

To manage daylight, solar heat gains, glare, view, and heat loss through facades, shading devices may be mounted to the interior or external façade surfaces. The three fundamental designs for outside shading devices are HORIZONTAL, VERTICAL, OR EGGCRATE. It will be crucial to consider the quantity of sun penetration that is required during the warmer months when building shade devices for heat avoidance.

The effectiveness of shading devices will depend on the solar orientation of a given building facade. For instance, modest permanent overhangs are a very effective solution to shade south-facing windows during the summer when sun angles are high. The same horizontal device is ineffective in blocking late afternoon light from entering west-facing windows during the summer's peak heat gain hours. Vertical devices can effectively screen the sun's rays if they are striking the facade from the south-east or south-west. On slopes that face south, egg-crate are frequently employed as well. It is frequently preferable to "gang" the south-facing shade structures for economic and heat-reduction purposes. To give shade in the late morning and early afternoon when the sun is not at its peak, the shading device should be extended on each sides of the window opening.

2) Dynamic Shading Devices

They are a collection of adaptable components that, either manually or automatically, strive to improve energy conservation and user comfort. They are specifically divided into two major classes based on their motion typologies: simple motion type and complicated motion type. Both groups use passive and aggressive energyinvolvement tactics. The active technique requires energy input since it employs mechanical-based actuators, but the passive approach doesn't because it uses human control or sensitive surfaces that may modify their intrinsic qualities (material-based actuators).

When human comfort and energy efficiency were the primary goals, these kinds might be controlled automatically (without user inputs) or occupant-centrically (enabling user interactions) using passive (e.g., cables, rods) and active (electro-mechanical) actuators. They may change their size, position, or shape, and they primarily move by rearranging their geometrical patterns or modularity. Different kinds of materials, such as stiff, flexible, and elastic bodies, can be used to carry out mechanical actions. Three primary typologies may be used to describe basic transformations:

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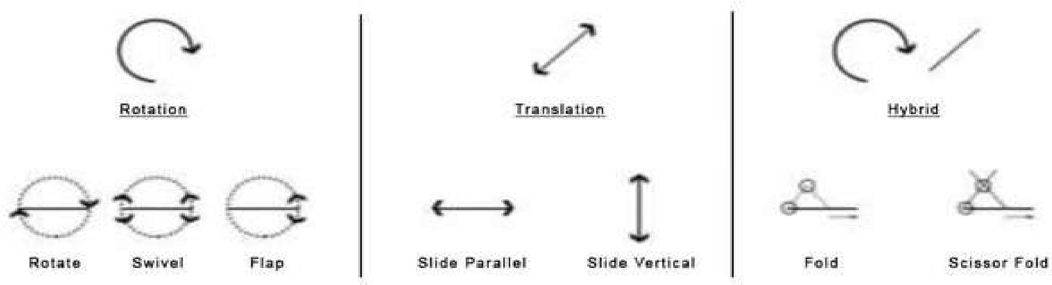

Fig. 8, Transformation Strategies used in Dynamic shading

- Translational motion that simulates sliding or other bi-dimensional form alteration
- Rotational motion, which refers to the transformation of a three-dimensional shape and can result in the three further typologies of swivel, revolving, and swing
- Expanding, contracting, folding, rolling, or twisting are examples of more complex movements that may be produced by combining translational and rotational motions.

3) Green Envelope

The use of vegetation on vegetated facades as a solar radiation blocker is advantageous since it prevents heat from radiating back into the area around the structure, in contrast to standard materials like metal or Meta-Plastic that do. The density of the foliage has a significant influence on how much of an impact it has. The temperatures of the different layers of a double-skin facade are frequently lower if plants are used against the inside slat region. Shade and aesthetic value are provided by the planted façade. Façade vegetation provides shadow effects comparable to other artificial systems with the added benefit of evaporative cooling, while needing some upkeep. Because of the natural shading provided by the flora, buildings' facades use less energy when it is covered with vegetation.

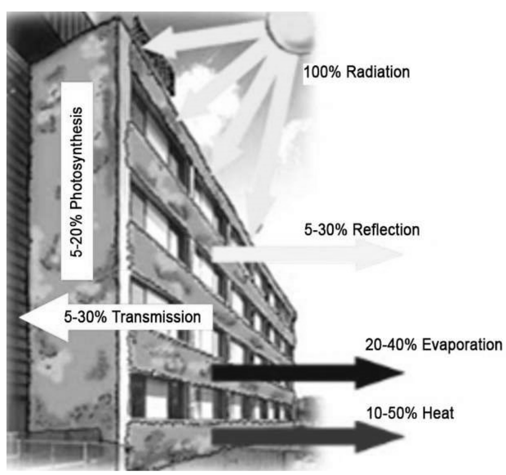

Fig. 9

C. Facade Systems

1) Double Skin Facade

Building facades with high glazing fractions can perform more efficiently in terms of thermal energy with the usage of double skin facades. It is made of inner glazing that is integrated into a curtain wall and outer glazing that is separated from one another. In the space between the two glass systems, it frequently has a controlled shade system. The primary architectural benefit of DSF lies in its transparency qualities, which allow for direct interaction with the building's surroundings and allow for a significant quantity of glare free daylight to penetrate the structure. Exterior & Internal glazed facade: The outer wall offers weather and sound protection. Spectrally-selective glazing is occasionally employed because it lets in daylight while limiting the transfer of solar heat into the structure. Internal facades include single or double glass panels that are thermally insulating, have sun control features, or have low-emissive coatings to prevent heat input, which may allow for natural ventilation in the offices.

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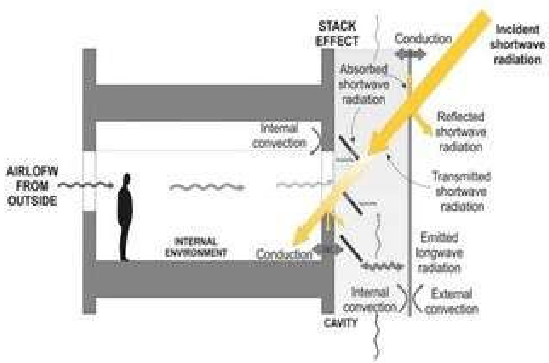
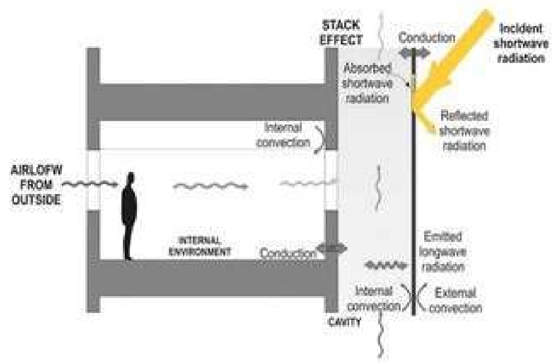
To create a complete screening or a cut-off, shading devices such as blinds, roller shades, louvres, motorized apertures, or fans are put in the hollow to enable diffused sunshine and reduce solar heat gain. In the tropics, the use of double-skin facades is a noteworthy option for several advantages, including a thermal buffer zone, solar heat gain reduction, energy savings, and aesthetics.



Outer layer made of Glazing



Outer layer made of opaque material

Fig. 10, Double skin Façade

IV. CASE STUDY SELECTION

Three literature case studies have been discussed in this paper in order to understand various passive and dynamic strategies that can be used in facade for composite climate.

A. The Arab World Institute, Paris

One of the most well-known and influential instances of kinetics in architecture is the Arab World Institute which was designed by architect Jean Nouvel in 1980s in Paris. The theme of light is reflected in the south facade as well as it offers privacy to occupants.

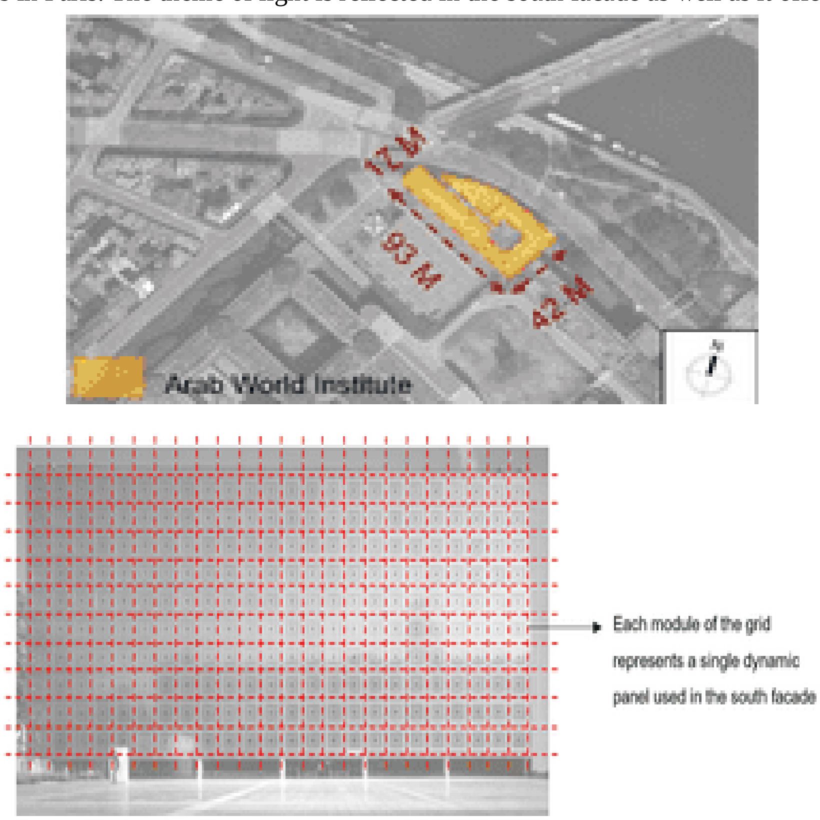


Fig. 11

1) Material

The southern façade reflects the motif of light. A metal frame on the front serves as a sun breaker. The institute has cutting-edge high-tech walls covered with mechanical apertures that change size in response to sunlight, either to limit solar exposure or to increase daylighting. An aluminium metal lattice that mimics the "mashrabiya" characteristic lattices found in the patios and balconies of the Arab nations covers the glass wall.

2) Component

A massive "mushrabiya" that merged high-tech modernism with conventional Arabian architectural form is the South façade, which measures 30 by 80 metres and consists of 240 panels. An electro pneumatic mechanism controls the elements' opening and closing, controlling the percentage of daylight between 10% and 30%. The delicate machinery is enclosed by 0.40 m broad frame frizes. About 2 metres square side tiles make up the facade. One primary iris and several secondary iris of two different sizes make up each tile's multiple iris. Each module is made up of 121 diaphragms of various sizes that are connected. A maximum of 18 movements can be made by the mechanism per day the photovoltaic cells first made the diaphragms photosensitive so they could work independently as light intensity rose.

These components of Jean Nouvel's façades were intended to function similarly to the camera's diaphragm, which alters the aperture's size to alter the amount of light that passes through it. Diaphragms would partially or completely close when the sun would hit the façade, raising the inside warmth. In this way, the façade would control the climate. Due to the installation of the diaphragm modules between two glass panels, this may be achievable. While the exterior panel is composed of coloured insulting glass, the inside panel, which was made moveable for maintenance, is made of single glass. The modules, which function as a sun shading system, are weatherproofed by enclosing them inside the façade system.

A diaphragm is made up of a base plate, a ring-shaped plate (the blade actuating ring), and many blades. There are as many slots in the blade actuating ring as there are blades. The little blades have two spikes on each, and when the aperture is changed by rotating the diaphragm, one of them slips into the slot. The three aforementioned parts make up the Arab World Institute's façade, which is similar to a camera's diaphragm. Aluminium makes up the components of the façade modules. There is anything from four to nine blades.

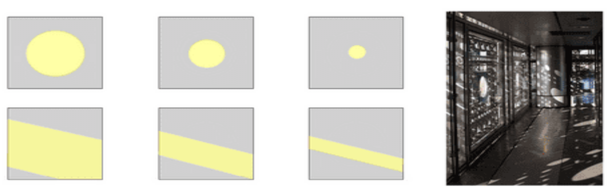


Fig. 12

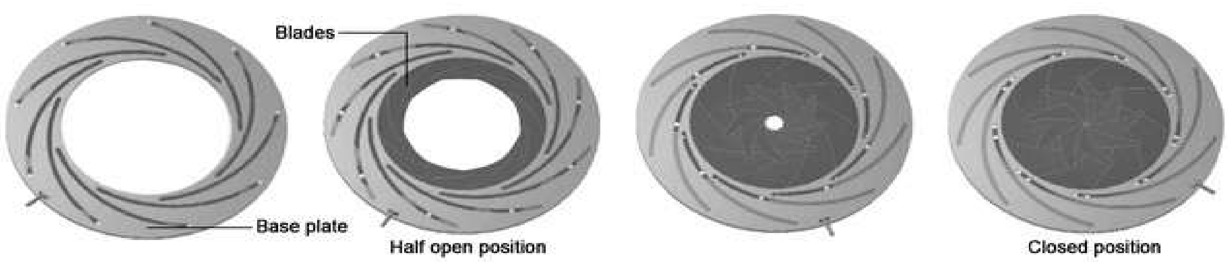


Fig. 13, Opening process of camera diaphragm

B. Hexalace, India

The open-plan commercial building known as Hexalace was built in 2018 in Mohali, India. It was obvious from the start that the design would need to be realized from the facade on a constrained commercial site with difficult building requirements. The building front facing west and the difficult climatic circumstances with intense heat caused the façade to develop as a stratifying element buffer.

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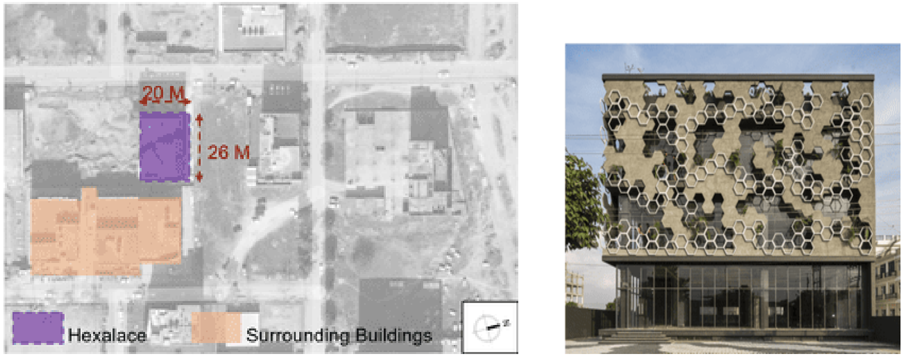

Fig. 14, Hexalace, India

1) Material
Due to the difficult weather circumstances, which included high heat, and the building's front facing west, the facade developed as a stratifying element buffer. Materials used are concrete and glass.

2) Component
A concrete layer three inches thick with hexagonal spaces between it has been employed as a shade feature. The screen moves organically to better preserve the sanctity of shade, providing a fascinating visual puzzle from both the inside and the outside. The semi-permeable concrete screen is stacked horizontally with a second layer of a hexagonal shaped metal frame which serves as fence for the balcony. Small groups of greenery are also housed on the balconies, providing light and shade.

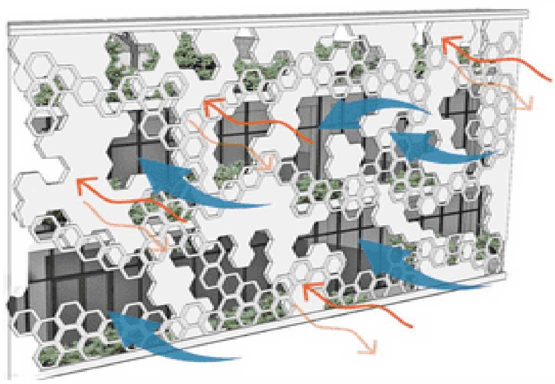
Fig. 15, Working of front façade

3) Facade System
There are air pockets between the screen and the main structure since the primary curtain wall has been recessed in order to lengthen the time lag and therefore decrease the heat gain. The facade serves as the building's bronchioles due to its intrinsic property of convergence.

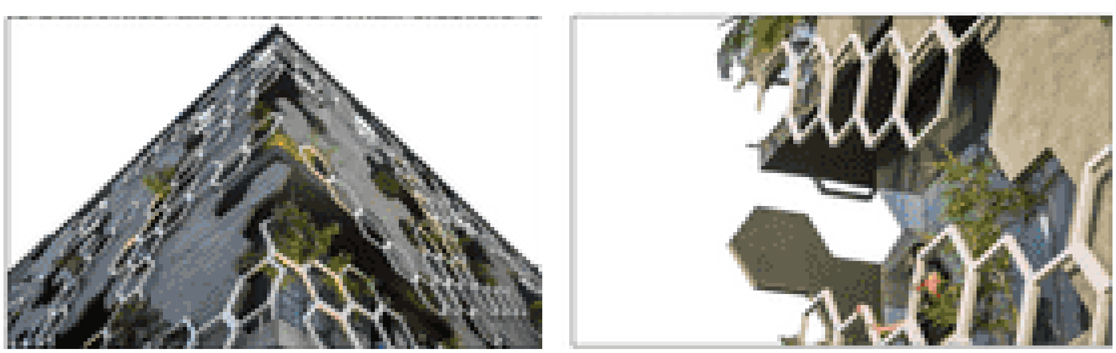
Fig. 16

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C. Development Alternatives Headquarters, India

This Institutional headquarters was built in 2008 in New Delhi, India. Located on the corner of the institutional area, the site is also bound by a dense forest reserve on two of its sides. The design shows how traditional sustainable architecture requirements may be completed while depending on affordable solutions derived from key local tradition teachings.

Fig 17

1) South Side Facade

The structure is shaded by vines trained on several faces to lessen heat gain. In addition to providing shade for the windows below, balconies and verandas serve as a transitional space between the inside and outside. The north and south sides' shade grills with plants and light reflectors reduce the intensity of the summer sun. All workplaces are lit by regulated sunshine that is distributed without glare. Allowed 150-200 lux of daylight.

2) West Side Facade

Design Strategies involve decreased exposed surface area, increased shading, increased surface reflectivity. Due to solar direction and perspective, each facade's design, particularly the fenestration, varies. Faced with the heaviest morning and afternoon light, those facing east and west are kept small and covered by sunscreen or the building volume itself. The west facade's windows have prism-shaped protrusions that act as blinders, blocking the hot afternoon sun while allowing views of the forest.

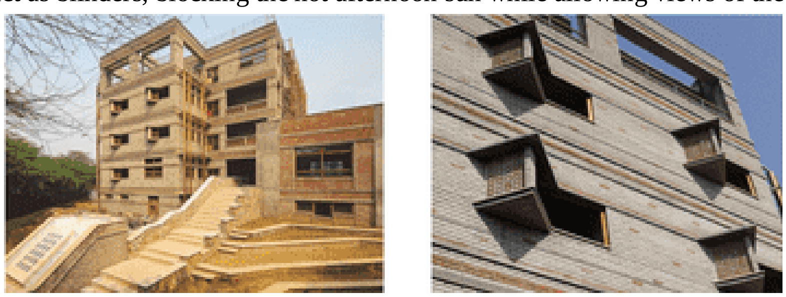

Fig. 18, Shading components on West side façade

3) East Side Facade

To prevent heat gain, vines climb the east and west walls as well as the pergolas. Only 20% of the visible area is made up of windows. Just enough light may enter the structure and heat can be reduced by the size of the windows. Windows with an adjustable venetian blind sandwiched between an exterior single-pane panel that is fixed and an interior sash that is movable.

V. COMPARITIVE ANALYSIS

Case Study	The Arab World Institute, Paris	Hexalace, Mohali	Development Alternatives Headquarters, New Delhi
Year	1987	2018	2008
Implemented Technology	Electro-mechanical Technology	Passive Strategies	Passive Strategies
Control System Technology	Central control	No control	No control
Sensing	Photovoltaic Sensors	No sensors	No sensors

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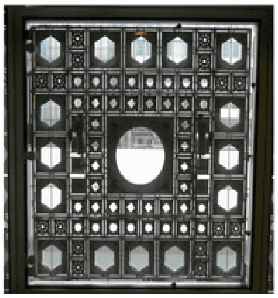
Technology			
Facade Material	Glass, Steel, Aluminium	Concrete, Glass	Fly-ash cemented blocks, compressed earth block, brick, cement, steel, glass
Component	Shading device- dynamic module resembling camera diaphragm. 	Shading Device – Organic shaped screen of hexagonal interstices 	Shading device - grills with planters and daylight reflectors, prism-shaped protrusions. 
	Size – 30X80 Meter Movements – 18 per day Daylight transition – 30%	Daylight area – 75%	Windows – 20% of total exposed surface
Facade System	Curtain Wall	Double Facade	

According to the study all three parameters are related to one another but can be prioritized as -

1) *Component:* Directly depending parameter for utilizing daylight and solar radiation.
2) *Material:* Along with component influences daylight and solar radiation.
3) *Facade Systems:* Supporting structural system for required component.

A. Appropriate Technologies

1) *North Façade:* Larger windows can be placed, as the north side experiences minimum radiation, for better and glare free daylighting. Use of glass with smart materials capable of changing their optical property including thermochromic, electrochromic, photochromic. Use of low emissivity glass.
2) *East Façade:* Low sun angle, openings must be small and adequately shaded. Use of various passive shading componentsZincluding horizontal, vertical, egg-crate type and green envelope components.
3) *West Façade:* Low evening sun, minimization of openings is desirable. Use of various passive shading components including horizontal, vertical, egg-crate type and green envelope components.
4) *South Façade:* Openings with adequate shading is preferred as in summer it has high sun angle and in winter it has low sun angle. A layer of permanent shading with green envelope or dynamic shading technology through the use of curtain wall.

VI. CONCLUSION

In this study, various facade systems have been considered for composite climate to utilise solar radiation and daylight. The design methods studied may be broadly categorised into two groups: (1) those depending on the usage of passive strategies for shading, e.g., louvers, vertical fins, green facades, balconies, overhangs; and (2) those depending upon material and technological advancements to achieve design goals, e.g., dynamic shadings. Balconies with curtain wall shading can create less glare and more comfortable working conditions in composite climate.

According to the results of the current study, there are alternatives for a number of parameters that can be used to create a facade that allow to utilize daylight, has high occupant satisfaction with respect to the thermal and visual environment, and the lighting utilises the least amount of energy overall. The study highlights the value of employing various climate response strategies to handle various issues. Different strategies could work better at certain time of the year or need to be paired with other tactics to be more effective.

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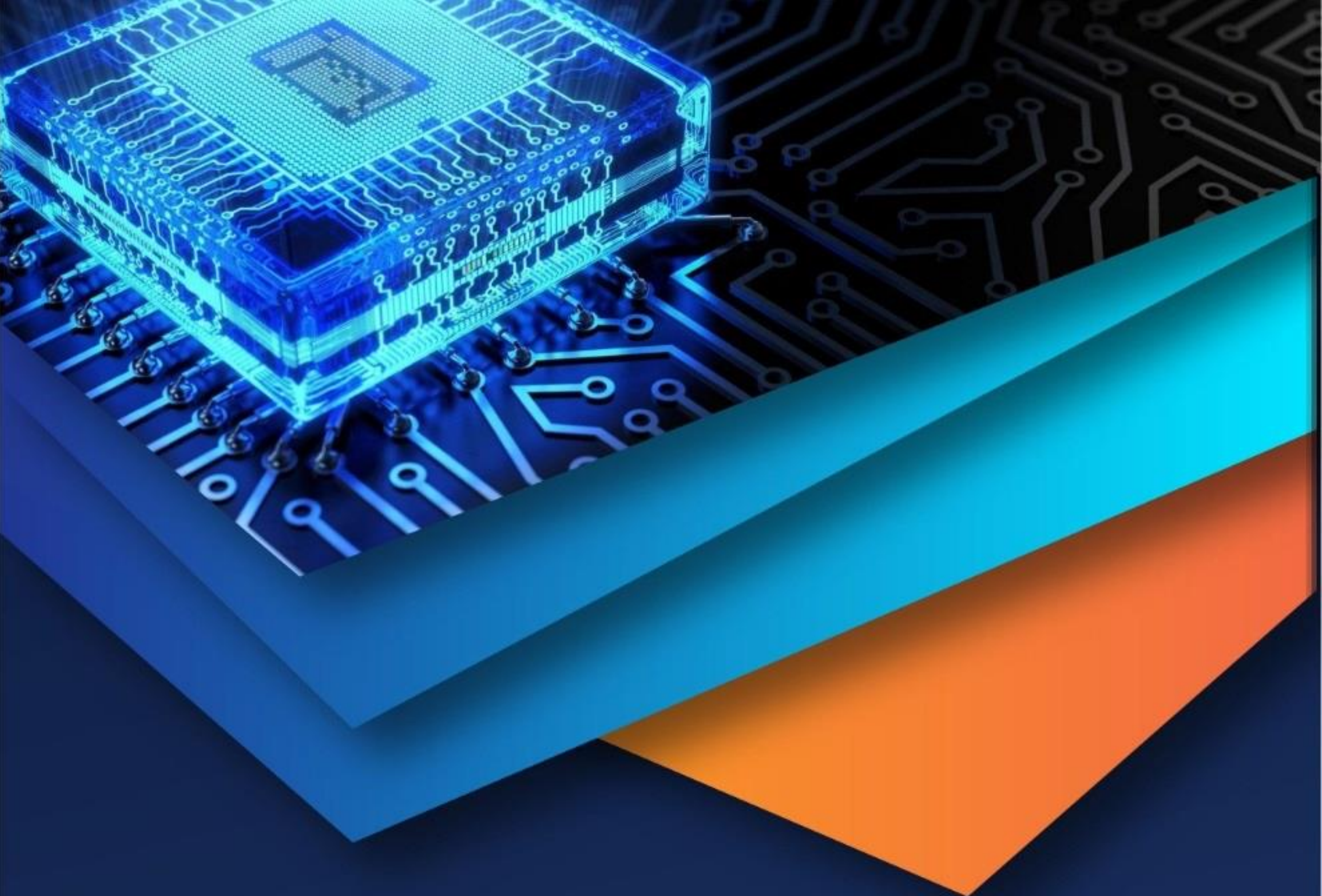

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