Energy-Efficient Retrofitting with Kinetic Shading Device in Tropical Climate

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Abstract - *The purpose of this study is to examine the potential of kinetic envelopes for the development of optimal, daylight-efficient facades. The research covers an extensive study on building façade journals and case studies. The retrofitting study involves the identification of commercial buildings in a hot and humid climatic region and perform daylight analysis on the building models. A commercial building was selected in Chennai and modelled through Rhino and daylight analysis was simulated in Climate Studio. The simulation was done with 3 cases: Varying Glazing Type & WWR (40% & 60%), Adding Kinetic Louvers & Adding Kinetic Louvers on WWR 40%. Base case was an envelope with Single Glazed Blue Tinted Glass. The results were analyzed based on LEED rating system with ASE and SDA values. Results showed that* ***Kinetic louvers with Single Glazed Blue Tinted glass*** *outperformed all the other cases. The best case decreased ASE by 65% and SDA by 30% from the base case. With increasing necessity for sustainable buildings and uncertainty of nature manifests, dynamic envelope retrofits for existing buildings like the best case discussed here can be seen as better options than relying on demolishing and re-constructing.*

Key Words: Kinetic louvers, retrofitting, daylight-efficient,

SDA - Spatial Daylight Autonomy

ASE – Annual Sunlight Exposure

LEED - Leadership in Energy and Environmental Design

WWR – Window Wall Ratio

ECBC – Energy Conservation Building Code

1.INTRODUCTION

A kinetic facade is a building facade that has the ability to move or change shape. These facades are designed to respond to environmental conditions such as temperature, humidity, wind, and light. The movement can be triggered automatically through sensors or manually through user input. Benefits of façade include temperature regulation & natural ventilation by opening and closing, reduce need for artificial lighting, visual dynamic appearance, aesthetic appeal, etc. They are made up of shape-memory alloys, hydraulic systems, flexible membranes, etc.

Nature manifests through climate changes are inevitable. Adaptation to such manifests is the best solution. The building sector accounts for a significant portion of global energy consumption, underscoring the importance of raising awareness about the energy efficiency of existing structures. Commercial buildings are a major contributor to this energy consumption, with office buildings standing out as having the highest energy usage rates within the commercial sector.

1.1 BACKGROUND OF THE STUDY

The energy performance of a building is influenced by several factors, such as the design of the building envelope, the behaviour of occupants, and the heating, ventilation, and air-conditioning (HVAC) system. Building facades are responsible for almost half of the energy consumption in buildings, either directly or indirectly. The building facade is a critical element in regulating the microclimate around a building, and can play a significant role in reducing energy consumption and mitigating negative environmental impacts.

Due to the longer operating hours and the substantial energy demands for lighting and temperature regulation, there is great potential for reducing energy consumption in office buildings by improving the daylight performance of their building envelopes. Retrofitting existing buildings can be an effective way to achieve this goal. The practice of retrofitting buildings for improved energy efficiency is still relatively new, and there has been limited focus on retrofitting building facades specifically. In fact, only 17% of retrofit projects conducted by Energy Savings Companies (ESCOs) involve upgrades to the building envelope. This research involves venturing into this new retrofit domain with kinetic facades.

1.2 AIM, OBJECTIVE AND SCOPE OF THE STUDY

The aim of this research is to analyse how kinetic shading system reduces energy consumption, identify low performance commercial buildings in Chennai city and improve its daylight performance using kinetic façade.

The objective of the study is to analyse the daylight performance of structures with kinetic shading systems. From the findings of the analysis, implement kinetic façade suitable for retrofitting in the site and simulate the implementation. Derive the daylight performance of the simulated structure. Compare the implementation with base case and evaluate the energy efficiency metrics.

The scope of the study is to identify the role of shading system in reducing energy consumption, find out ways for improving building's environmental performance and demonstrate the ways to use natural lighting effectively.

2. METHODOLOGY

In this research, case studies on kinetic shading systems, energy performance, and relevant design and control strategies were analysed. Collection of data on the energy performance of existing structures with kinetic shading systems in different climatic conditions. Analysis of the collected data to identify the factors that influence the energy performance of kinetic shading systems. Simulate the best shading system implementation from the analysis and derive the daylight performance of the structure. Recommend the inferences gained from the analysis and simulation.

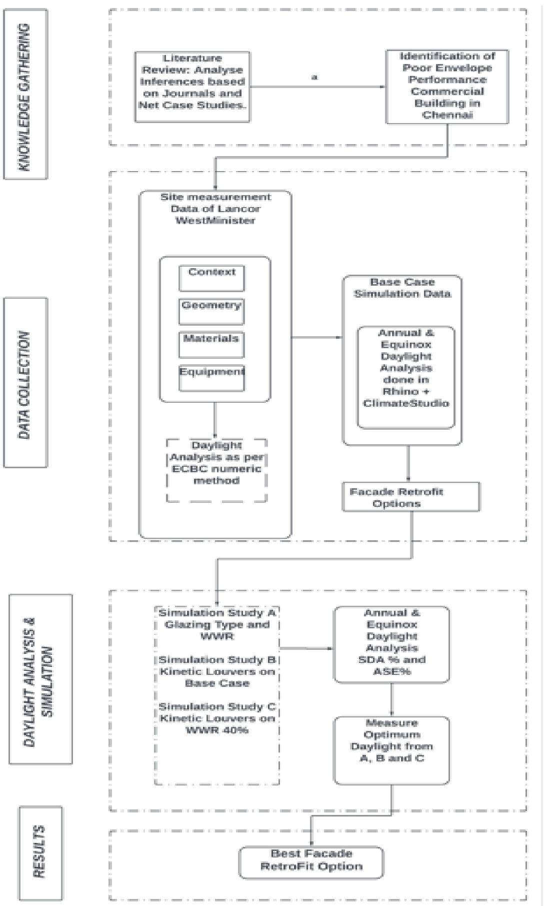

Chart- 1: Methodology

3. LITERATURE REVIEW

Appropriate journals related to kinetic shading system published between 2014 and 2022 were reviewed.

In a study by **Hosseini *et al.*, 2019**, a kinetic interactive façade was developed in order to meet visual comfort. The simulation results showed that the kinetic interactive facades outperformed the base case in terms of improving visual comfort. Contrary to the base model, the majority of the scenarios for the predicted risk of glare are in the imperceptible and perceptible ranges, with percentages of 63.9% and 22.2% for the 2D-SCF (Shape Change Façade), respectively. The 3D-SCF, however, exhibits an exceptional performance. Precisely, 86.1% of the scenarios locate in imperceptible and 13.9% in perceptible range without any scenarios in the disturbing and intolerable area.

On applying different computational models of kinetic façade patterns to a generic building, it can be inferred that the kinetic facade system can be used to create and provide completely dark spaces according to the user's request, while it can be used in a completely open configuration after sunset. As a result, the proposed system and method were effective in daylight control and resulted in much better results than the initial model. **(Kizilörenli *et al.*, 2022)**

A kinetic shading system was created with independent units parametrically in response to sunlight via 3D rotation (around the centre of the units) and 2D movement (on the shading system's surface). In the research by **Samadi *et al.*, 2020**, 4D configuration of the shader system was the most important one that enabled it to have very precise and efficient adjustments based on sun position in the sky. Further enhancing the accuracy of system performance was the independent configuration of each unit of the system based on the position of the sun and the desired point on the ceiling. Limitless options were made possible by the variety of shade shapes, 3D rotation, and 4D performance, which is significant for the architectural design of shaders by supplying the proper aesthetics and functions in the designs they create. One way to achieve the goal of developing intelligent building equipment was to control the shading system depending on the environmental conditions.

The green facade reduces HVAC load and gives the oxygen by the process of photosynthesis, a vertical vegetation cover could lower the temperature of a facade wall and buffered its fluctuation with time, leading to reduced power loading air-conditioning. The use of vegetation and Dynamic Facade, can be a useful tool for passive and active thermal control of buildings with the consequent energy saving. This can happen in four ways that are frequently connected: thermal insulation, solar radiation interaction, shade, evaporative cooling, and variations in the wind's force on the building **(Mansoor *et al.*, 2018).**

The experimental results analyzing the thermal performance of residential building coupled with smart kinetic shading system indicated that the system decreased indoor air temperature by 2-3°C in the summer season. Consequently, it reduced thermal load that led to saving energy by 20%. Therefore, it can be inferred that electricity consumption in summer months after installing the proposed system was lower than the consumption under actual operation conditions **(Ahmed *et al.,* 2016).**

In a study by **Bacha *et al.,* 2016**, the impact and effectiveness of smart façades on indoor thermal comfort and energy efficiency were assessed. The findings demonstrated that the integration of a dynamic sun protection system reduced the exposure to direct radiation by 17.9%, acting as a second skin and directly influencing the levels of thermal and visual comfort. The energy consumption is significantly decreased by this dynamic shading system, reaching a reduction of 43%, and indoor air temperature is decreased by 4.0 C° to 4.8 C°. Additionally, the incorporation of solar energy cells into the kinetic façade contributes favorably to the generation of electricity.

The use of kinetic facades allows for efficient energy maximization in buildings and complete climate adaptation, giving residents the utmost comfort as the seasons change. The building where kinetic façade should be implemented needs to be responsive to the climate context, and since the building envelope is the boundary between the external atmosphere and the interior, the layout of the envelope becomes a key factor in the development of sustainable and energy-efficient buildings **(Ibrahim *et al.,* 2019)**

Shen *et al.,* 2019, proposed a "Parametric Adaptive Skin System" (PASS) based on BIM aided computation. The interaction of PASS can satisfy both immediate changes in microclimate and ongoing seasonal constraints through the combination of physical and virtual sunlight parameters. The PASS prototype shows that the process is successful in driving the interaction between the virtual Revit simulation and the actual PASS model by using a real light detector along with simulated solar terms.

By integrating photovoltaic modules into an adaptive shading system, the facade is able to generate its own electricity in addition to solar shading. In addition to adaptable biomimetic facades, adaptive solar facades can be used to save an additional 25% of energy. Kinetic Facades have the potential to integrate all the following functions together: thermal and visual comfort, reducing artificial light, sun tracking and reducing electricity. The blade size and louvre spacing are discovered to be the most significant factors influencing the objective performance for louvre type facades.

Ali *et al.,* 2019 found that the double skin façade seems to be well responsive to the climatic issues but will only be efficient for warm and humid climate if the building design orientation and room placement are appropriately placed for optimal response to sun and wind & will provide protection from solar radiation where required.

4. NET CASE STUDIES

4.1 Al-Bahr Towers, Abu Dhabi

Figure - 1: Al-Bahr Towers at Abu Dhabi

Location and climate:

Abu Dhabi is familiar with its hot desert climate where the average temperatures during the summer and winter months are above 38 °C and around 18°C. The average annual hours of sunshine per year is 3609 hours with an average of 9.9 hours of sunshine per day.

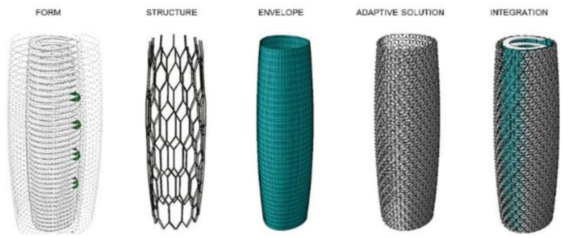

Figure - 2: Facade of Al-Bahr Towers

Concept & description:

Dynamic mashrabiya refers to an unfolding and folding concept that is inspired by historical events and adaptable natural systems. This façade has three kinetic states: totally closed, mid-open and fully open.

Each shading device consists of a microfiber-coated triangle-shaped screen. This solar shading is dynamic and modular, with 1049 modules for each tower. It is actuated by sun tracking software that controls the folding and unfolding movement of the elements according to the sun position.

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Control Mechanism:

A linear screw-jack actuator and an electric motor with triangular facets that fold into the centre, work according to a pre-programmed sequence. Sun movement is simulated by an embedded pre-set programme. The actuator exerts its own self-equilibrating forces, which are not transferred to the support structure. Automatically by BMS, which computes the state of each module in response to data sent by light & anemometer sensor for measuring wind speed.

Figure – 3: Al-Bahr Towers Structure Description

Benefits of the façade:

50% energy savings-office spaces alone, & up to 20% for the building overall; 20% reduction in carbon emission with up to 50% for office spaces use alone (reduction in AC & lighting usage); 15% reduction in overall plant size and capital cost; 20% reduction in materials and overall weight due to the highly fluid, rational and optimized Design.

Inference:

Through the use of this innovative kinetic system, it was found that heat gains and glare occurrence were reduced by 50% whereas the daylight penetration was improved leading to less dependence on artificial lighting which resulted in CO2 emissions reduction by 1,750 tons per year.

4.2 Thyssenkrupp Quarter Essen, Germany

Location and Climate:

Essen has a generally temperate climate with mild winters and cool summers. The warmest months have high temperature of 22.3°C while the coldest months are with average low temperature of 2°C. Essen have an average of 1454 hours of sunshine per year.

Concept and description:

Important objective of the design was to achieve energy efficiency and sustainable use of resource. The sunshade elements have been manufactured by using a chromium- nickel-molybdenum stainless steel. It consists of 3150 vertical twisting fins. Each of the twisting fins can twist independently and reach the position between 0° and 90°.

Figure - 4: ThyssenKrupp Essen

Embedded Computation:

In accordance with the movement of the sun, engines are used to centrally control all of these components. The control panel not only recognizes the changing sun position but also knows the current weather conditions.

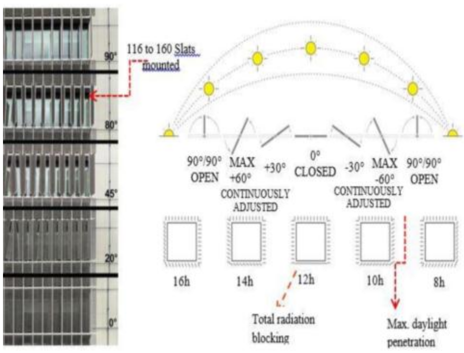

Figure - 5: Essen Control mechanism of façade

Control Mechanism:

A linear motor powers the dual axle to which the wooden slats are attached. Slats rotate on a vertical axis and move with the position of the sun. There are 1,280 motorised elements in total, 3,150 routed stainless steel movable stalks, and 400,000 metal "Feathers" anchored to them. Two factors influence movement: Seasonal movement – Sun. Real time measurement–Roof which sends data to Meteorological station

Inferences:

Tracking the sun position in addition to real-time measurements of weather conditions is basis of the shading system adaptiveness, thus the façade can be considered as a solar and heat adaptive kinetic façade.

4.3 Kiefer Technic Showroom, Bad Gleichenberg, Austria

Figure - 6: Kiefer Technic Showroom

Location and Climate:

The climate is warm and temperate with average temperature between -1 in winter and 20 degrees in summer. The average annual sunshine hours are around 1820 hours per year.

Concept and description:

Dynamic façade that adapts and change its configuration depending on the outside changing conditions and the user needs. The south façade of the building is composed of two layers: inner static one made of glass and an outer dynamic skin. The 122 aluminium panels that make up the façade are that which is moving the most. These panels fold and unfolds by sliding up and down when converting between different states of openness. Thus, the façade becomes a kinetic sculpture called "dancing façade".

Rotating Panels Façade:

The building was exposed and sealed using 122 rotating panels. Motors set at each bay are connected to panels, which allow them to rotate in a variety of patterns.

Control Mechanism:

An intricate network of hinges, guide rails, and electric motors is used to move the aluminium panels that make up the dynamic façade. It can be set up to move either automatically or manually.

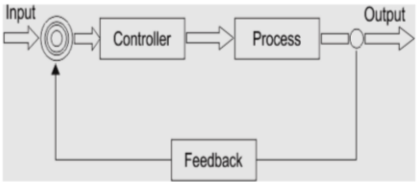

Figure - 7: Kiefer Showroom Control Mechanism

Inferences:

Kiefer showroom façade is also a solar and heat adaptable kinetic façade as the kinetic panels control the amount of light and heat that enters the space. The façade is more a showcase for the company products than a responsive shading system.

5. PROPOSED SITE STUDY & ANALYSIS:

Lancor West Minister, located in RK Salai, Chennai. West Minister is an office building located in Mylapore, Chennai. It is G+9 Structure of total height 31m. It has a rectangular plan with the longer side-oriented east-west direction. It has a fully glazed façade with a curtain wall system of grid size 1524 x 1030 mm of aluminium frame and 6mm single reflective glass

Figure - 8: Site Image

	Site detail	Data
Building Level	Site area in sqmt - area of the site	1736 m2
	Total gross area - sqmt	6569 ft2
	% Core area: area of lifts, staircase, toilets and other services in one floor	18%
	FTF in mts: Floor to floor clear height	2.85m
	DOF in mts: Depth Of the Floor from window to window line	18m
Envelope Level	Glazing U-factor (W/m2-K)	5.82
	SHGC - Solar Heat Gain Coefficient for glazing	0.46
	WWR %: Window to wall ratio for total façade area	74%
	VT: Visual transmittance of the glass	0.25

Table - 1: Site Details

Façade Direction	Total façade area	Total Glazing area
North-South	1116m2	918m2
East-West	2108m2	1482m2
Total	**3224m2**	**2400m2**

Table - 2: Site Façade Details

This building's envelope is single glazed in all 4 directions. East and West directions receive harsh daylight & high glare probability as it is fully glazed with Window to Wall Ratio (WWR) as 75% whereas ECBC norms recommend 40% only.

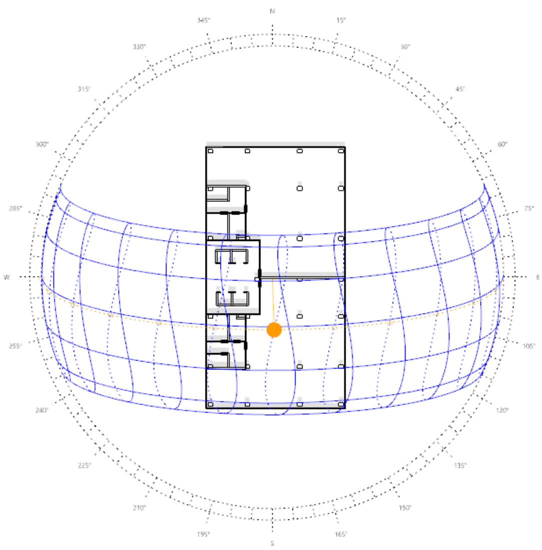

Figure - 9: Site Analysis

6. DAYLIGHT SIMULATION & ANALYSIS:

Daylight Simulation & Analysis is done in Rhino and Climate Studio.

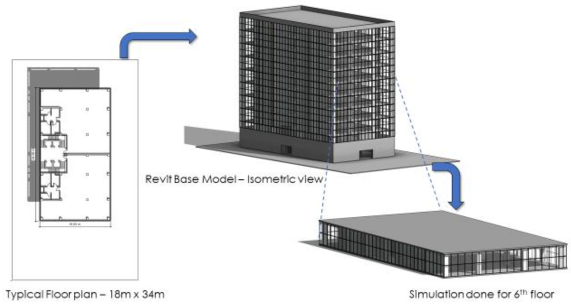

Figure - 10: Simulation Model

Simulation Parameters: Reference plane at 30 inches from the floor (0.762m). Internal partitions, blinds, and shades are not included in the model. Lighting thresholds as specified by the standard (sDA: 100 lux for 50% of the time and ASE:1000 lux for more than 250 occupied hours per year). Analysis grid is 0.6 × 0.6 m.8 am to 6 pm – a total of 3650 hours.

LEED V4.1 DAYLIGHT - It simulates daylight availability throughout the entire year.

LEED V4.0 DAYLIGHT - On the equinox, at 9 a.m. and 3 p.m., it simulates the presence of daylight. Every time, the sky condition is based on the day that is brightest in the weather file that is within 15 days of either March 21 or September 21.

Simulation is done with 3 cases:

- Varying Glazing Type and WWR
- Applying Kinetic Louvers on Base Case
- Applying Kinetic Louvers on WWR 40%

The simulation results are analysed based on SDA – Spatial Daylight Autonomy and ASE – Annual Sunlight Exposure. Every year, SDA evaluates whether a space acquires enough natural light on a work plane throughout normal business hours. The goal is 300 lux for 50% of the time that is spent in use.

Surfaces that receive excess direct sunlight may result in eye discomfort (glare) or higher cooling costs, according to ASE. For LEED v4.1, no more than 10% of a space should have direct sunlight. WWR – Window to Wall Ratio 40% and 60% were utilized for simulation cases.

IND_Chennai-Madras.432790_ISHRAE	Data
Climate Zone of Koeppen	Tropical Savanna, Dry Winter (Aw)
ASHRAE climate zone	Extremely hot

Average annual temperature	28 °C
Annual total solar radiation	1,764 kWh/m2
Coldest month	January – 18.7°C
Hottest month	May - 38 °C

Table - 3: Site Analysis

Surface Type Reflectance Wall or Vertical Internal Surfaces	50%
Ceiling	70%
Floor	20%
Double Glazing- Visual Transmittance	80%

Table - 4: Simulation Parameters

The base case envelope is Single Glazed Blue Tinted. Figure 11 shows the model of the base case envelope implemented in Rhino. The ASE and SDA for the base case are 88.8 and 28.5 respectively. The values show that daylight performance of the building is poor as per LEED and ECBC standards.

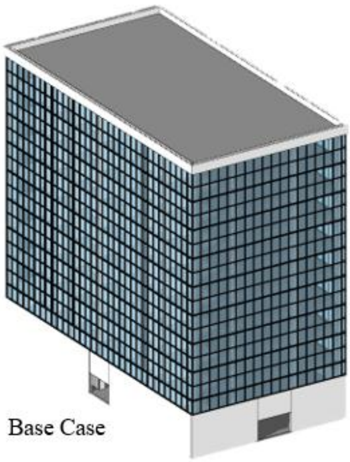

Figure - 11: Base Case: Single Glazed Blue Tinted Glass

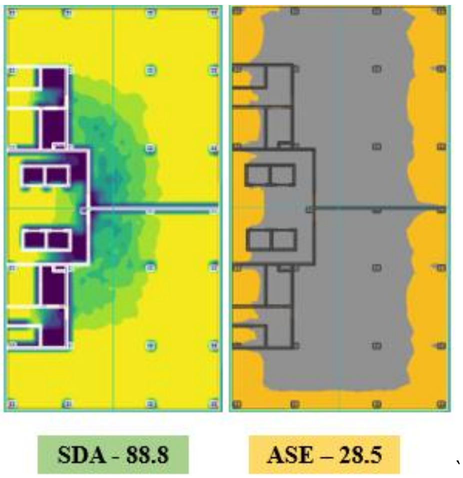

Figure - 12: SDA & ASE of Base case

6.1 CASE 1 - Varying Glazing Type & WWR:

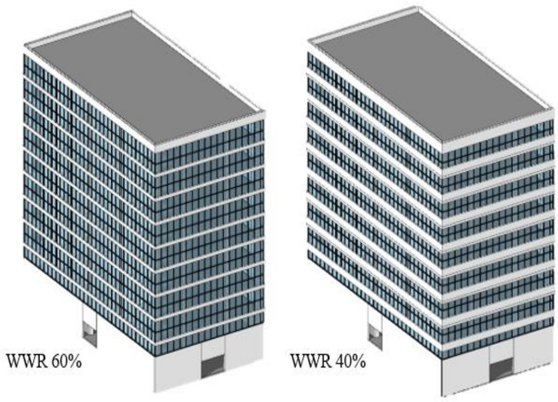

Figure - 13: Window to Wall Ratio 40% and 60%

OPTIONS	TYPE	Glazing type	SDA	ASE	LUX	9.00AM	3.00PM	LEED4.1	ECBC
Glazing Type	1a	SG- Tinted glass	88.8	28.5	1590	73.5	70.6	3	Yes
	1b	SG- Reflective glass	56.5	19.9	588	46.85	46.3	2	Yes
	1c	DG- Tinted glass	60.8	21.1	706	54.3	52	2	Yes
	1d	DG- Reflective glass	49.2	16.2	463	41	41.5	1	Yes
WWR 60%	2a	SG- Tinted glass	83.5	27.4	1488	72.2	65.8	3	Yes
	2b	SG- Reflective glass	53	19	522	44.3	44.9	1	Yes
	2c	DG- Tinted glass	59	20.4	700	53.3	49.8	2	Yes
	2d	DG- Reflective glass	47.5	15.7	458	39.4	40.3	1	Yes
WWR 40%	3a	SG- Tinted glass	74.1	24.9	1360	71.8	59.7	2	Yes
	3b	SG- Reflective glass	46.5	18.2	494	38.9	39.03	1	Yes
	3c	DG- Tinted glass	51.9	19.2	591	46.5	44.9	1	Yes
	3d	DG- Reflective glass	40.3	13.8	385	30	34.8	1	Yes

Table - 5: CASE 1 – Simulation Results

Two kinds of glasses were analysed: Tinted (base case) and Reflective. Single and Double glazing were applied to these 2 glasses. These test cases were then varied with Window to Wall Ratio of 40% and 60%.

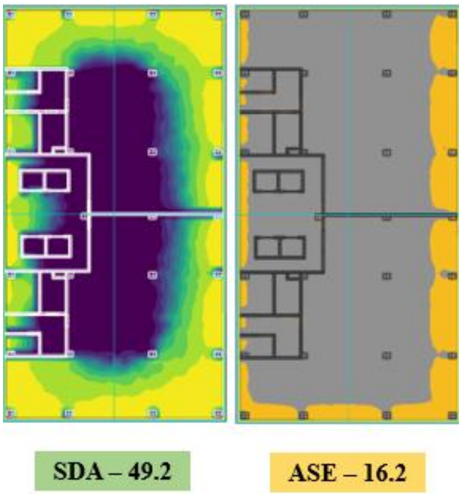

Figure - 14: SDA & ASE of Double Glazed Reflective

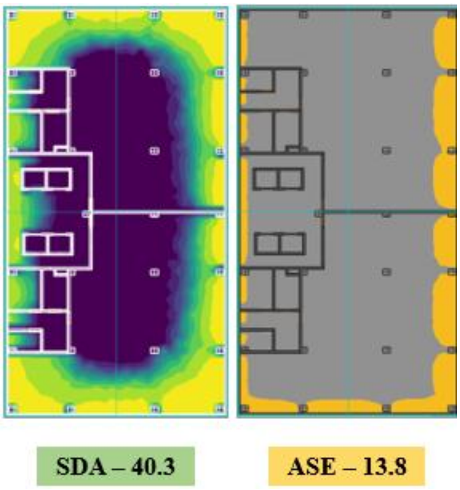

Figure - 15: SDA & ASE of Double - Glazed Reflective Window to Wall Ratio 40%

6.2 CASE 2 - Applying Kinetic Louvers:

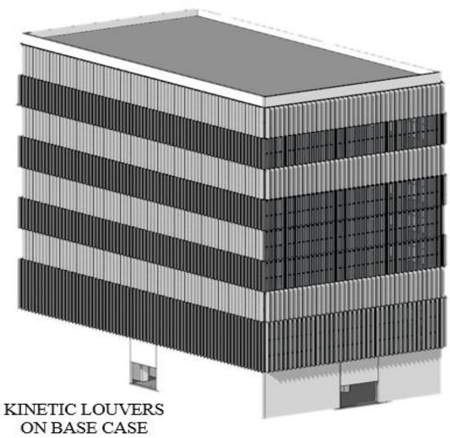

Figure - 16: Kinetic Louvers applied on Base case

OPTIONS	TYPE	Glazing type	SDA	ASE	LUX	9.00AM	3.00PM	LEED4.1	ECBC
GLAZING TYPE	1a	Base case	88.8	28.5	1590	73.5	70.6	3	Yes
WWR 40%	3d	DG- Reflective glass	40.3	13.8	385	30	34.8	1	Yes
Kinetic Louvres	4a	SG- Tinted glass	62.2	9.7	715	63.8	59.5	2	Yes
	4b	SG- Reflective glass	43.2	8	352	37.5	36.2	1	Yes
	4c	DG- Tinted glass	49.5	9.3	444	45.4	43	1	Yes
	4d	DG- Reflective glass	37.2	6.2	308	29.2	33.6	0	No

Table - 6: CASE 2: Kinetic Louvers applied on Base case

Kinetic louvers simulated in this study are vertically framed and made of lightweight aluminium composite panels with a depth of fins of not more than 0.6 m and 30% light reflectance. The curtain panels already in place are integrated with the shading elements. These louvers are controlled by pneumatic actuators/motors which convert air to mechanical motion. These louvers can be easily maintained and comparatively lesser cost than other shading devices.

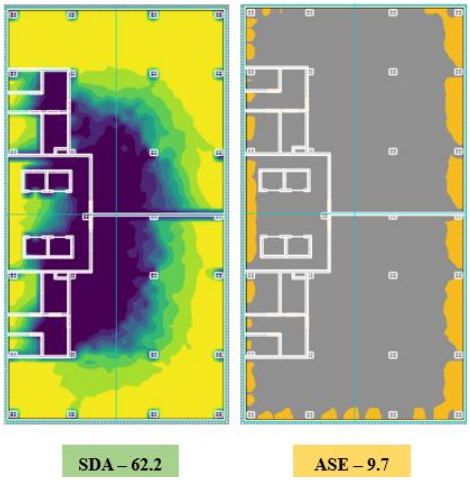

Figure - 17: SDA & ASE of Double Glazed Reflective Window to Wall Ratio 40%

6.3 CASE 3 - Applying Kinetic Louvers with WWR 40%:

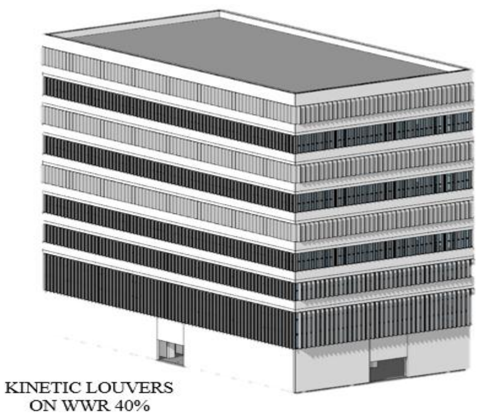

Figure - 18: Kinetic Louvers applied on WWR 40%

Kinetic Louvers with WWR 40% were applied for Single- & Double-Glazed Glasses. Two kinds of glasses were analysed: Tinted (base case) and Reflective. Single and Double glazing were applied to these 2 glasses. These test cases were then varied with Window to Wall Ratio of 40% and 60%.

OPTIONS	TYPE	Glazing type	SDA	ASE	LUX	9.00AM	3.00PM	LEED4.1	ECBC
GLAZING TYPE	1a	Base case	88.8	28.5	1590	73.5	70.6	3	Yes
WWR 40%	3d	DG- Reflective glass	40.3	13.8	385	30	34.8	1	Yes
Kinetic Louvres	4a	SG- Tinted glass	62.2	9.7	715	63.8	59.5	2	Yes
Kinetic Louvres WWR40 %	5a	SG- Tinted glass	55.8	9.3	657	56.3	51.6	2	Yes
	5b	SG- Reflective glass	36.1	9	318	30	32	0	No
	5c	DG- Tinted glass	40.1	9	341	38	36	1	Yes
	5d	DG- Reflective glass	29	6.4	265	21.2	28.2	0	No

Table - 7: CASE 3: Kinetic Louvers WWR 40% applied on Base case

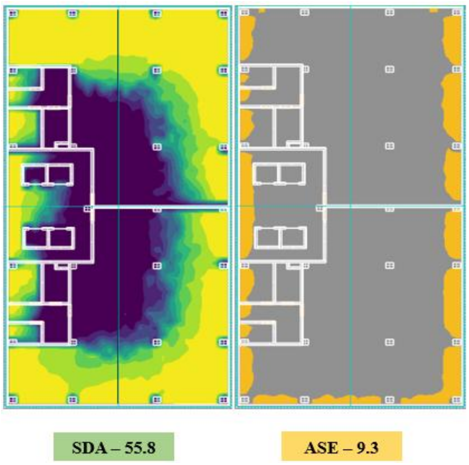

Figure - 19: SDA & ASE of Double Glazed Reflective Window to Wall Ratio 40%

7. Results and Discussions:

Figure 21 shows the SDA and ASE values for the base case and the best cases of 3 simulation studies. The thresholds for SDA and ASE are considered as 75% and 10 respectively.

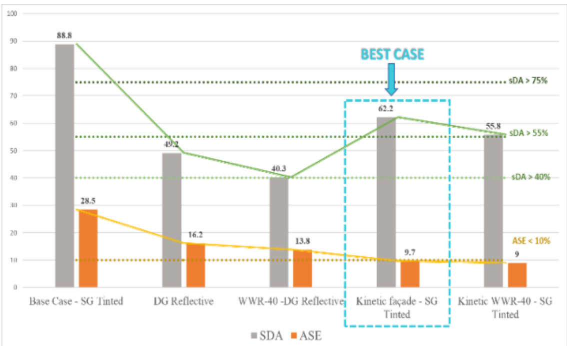

Figure - 20: Comparison of Best Case and Base Case

With Kinetic facades, normal Single Glazed Tinted envelope gives the best ASE and SDA pair. Single Glazed Tinted Kinetic Envelope has decreased ASE by 65% and SDA by 30% from the base case. As per ECBC norms, WWR 40% is required. So Kinetic façade on Blue Tinted Glass with WWR 40% is best which decreases ASE by 68% and SDA by 37%.

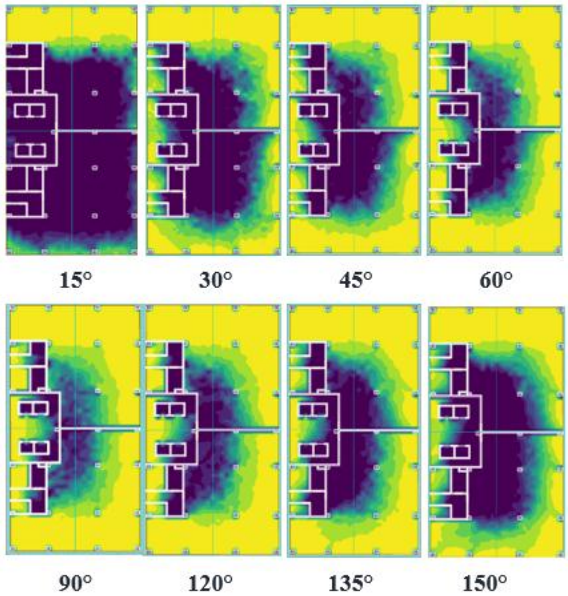

Figure - 21: Best Case – Single Glazed Blue Tinted with Kinetic Louvers at different angles

ANGLES	SDA	ASE	Average LUX	9.00AM	3.00PM	LEEDV4.1
15	26	0.6	279	32.3	21	0
30	51.2	2.3	509	59.4	50.3	1
45	60.4	5	660	67.9	59.8	2
60	68.2	16.5	844	75.1	61.3	2
90	76.4	18.4	958	74.6	63.3	3
120	68.7	16.5	902	71.9	60.3	2
135	62.2	9.7	715	63.8	59.5	2
150	53.2	3.6	522	54.7	51.9	1
165	30	0.8	324	30.9	32.1	0

Table - 8: Best Case - Single Glazed Blue Tinted Kinetic Louvers at different angles

The above figure represents the daylight performance when the kinetic louver turns in different angles. Due to cost constraint issues, if it is not feasible to implement kinetic louvers, then these angles can be fixed and louvers can be implemented as static. Among the angles, 135^0 gives the best daylight performance.

7. CONCLUSIONS

Achieving a balance between natural lighting and occupant comfort is crucial to optimize energy consumption and ensure a sustainable workspace. Low SDA and ASE values can result in higher energy consumption and costs associated with lighting. High SDA and ASE values can cause discomfort for occupants, requiring additional cooling and shading strategies. Implementing a kinetic facade system can improve SDA and ASE values, resulting in reduced energy consumption and costs associated with lighting and cooling. To maximize natural daylight penetration and reduce solar heat gain and energy consumption, glazing systems with high VLT and low SHGC and U-value values should be selected. Single glazed glass typically has higher SHGC than double glazed glass, negatively impacting SDA and ASE. Tinted glass allows maximum daylight but increases the probability of glare, while reflective glass reduces glare but has poor daylight performance. According to the simulation results, it is inferenced that when SDA values increase/decrease, ASE values also increase/decrease and vice-versa. Three simulation studies showed that retrofitting existing spaces can improve energy efficiency. Double glazed systems performed well in the base case but poorly with WWR/kinetic louvers. Single glazed systems outperformed double glazed with WWR/kinetic louvers. This suggests that single glazed spaces in similar weather conditions/direction as the study site can improve energy efficiency by retrofitting the best cases from this study based on their ecological and economical requirements.

The utilization of natural daylight is an essential aspect of building design that enhances the spatial qualities, sustainability, and energy efficiency objectives of a structure. The emerging concept of kinetic architecture aligns with these goals by promoting the use of building elements that are adaptable to dynamically responsive facades. Retrofitting optimal and energy efficient envelopes for existing non-sustainable buildings are crucial. The findings from this study can also apply for buildings in construction phase. Most of the commercial buildings have blinds to prevent glare from daylight. These blinds will not be necessary as the louvers itself will prevent harsh light. Visual comfort will also be at its best. Island cooling and heating effect can be achieved automatically with kinetic facades.

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