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Evaluating the Energy Performance of different Glazing Systems for an Office Building façade and providing with the Economical Solution: A Case study in Warm And Humid Climate

Ayushi Gupta[1],*and Sheetal Bagde[2]
[1]PG Student, Department of Architecture,
[2]Assistant Professor, Department of Architecture,
Jawaharlal Nehru Engg. College, MGM University Aurangabad, India

***Corresponding author's e-mail :** ayushigupta0042@gmail.com, **Mob.** +91-9158707841

A B S T R A C T

Now-a-days, number of office buildings that use fully glazed façade system, tend to increase irrespective of the climate. The use of glass in building is necessary for daylight, ventilation and aesthetics.The building envelope substantially discrete interior from the exterior surrounding. In spite of the merits of glass façade, it still provides the lowest insulating values which results in more solar heat gain and energy consumption. Therefore, this issue needs to provided with some solutions. This paper aims to determine the most energy efficient glazed façade system for an office building in a warm and humid climate of Pune, India. It will help to decide the most suitable glass assembly for office building façade through an integrated assessment which combines both energy performance and the economics. An assessment can be applied on a real architectural project with Design Builder software. This software is employed for simulations where, the only changing variable is glazing system assembly and other factors like cooling, lighting, orientation & etc. are constant. As all façades of the building experiences different solar heat gain, so it is not mandatory to install a single type of glazing to whole building facade.

Keywords : *Glazed façade, SHGC, U-value, space cooling, economical aspects*

1. Introduction:

"Energy saved is energy created" Energy efficiency has become the growing concern of the economic activity in today's world. India's building energy consumption is increasing by 2.7% each year between 2015 to 2040, more than twice the global average increase has been found. India's total commercial building energy consumption to continue increasing, from 59% in 2015 to 65% in 2040 (EIA's IEO2017). Energy represents a major component in any country's economy and hence it affects the national economy. The footprint of commercial building in India is less but compare to other sectors it consumes more energy. Building energy consumption depends on many factors including the number of occupants, building orientation, the number of appliances used, air conditioners performance, window/opening materials, shading as well as the material of roof and walls.

Façade is a French origin word meaning the front face. The use of glass in outside facades provides more of sunlight and good ambience to the occupant of the building which gave rise to the increasing use of glass. For the architectural point of view the utilization of the glass allows aesthetic view to the building itself.

The way in which light transmits through a piece of glass in building can be a powerful design tool for an architect. Glass can reflect, bend, transmit, and absorb light, all with great accuracy. Most architectural glass is partly transparent with little reflectance and absorbency. There are hundreds of glass compositions as well as different coatings, colors, thick-nesses, and laminates, all of which affect the way light passes through the material.

1.1 Building Envelope :

Building envelope acts as a barrier between interior and exterior environment of building including wall, roof and fenestration. The building envelope plays a crucial role in regulating interior temperature and reducing the heat gain by the envelope. The fenestration systems build a visual connectivity to outside environment and also provide ventilation in building, at the same time they also acts as the weakest energy leaks of the building. Historically, due to the physical properties of glass like weather durability, aesthetic, transparency it has always been the ideal choice for window glazing over plastic. But now a days, there are many types available in market for glass with different properties and qualities. Choice of glazing type should be cautiously selected so that it can enhance the energy performance and reduces the energy consumption by decreasing the lighting, heating and cooling loads in building.

Further the energy performance of glazing systems is increasingly more vital as contemporary building pursue higher WWR. In addition, energy performance is directly affected by solar heat gain coefficient (SHGC), heat transmission (U-value), visible light transmittance (VLT) as well as air infiltration through quality workmanship. Glazing systems have advanced in a competitive way that need to reform and the way of choosing decision. Decision are not made through only picking the best properties or price, but a combination of measures and optimized performance area considered to ensure a balanced choice in terms of energy and economic performance. Glazing allows natural light and heat to transfer from outside to inside which effects on the building's energy consumption besides the comfort, heath and the productivity of the occupants. The glass is highly used as a cover for these openings due to its low cost and high transparency. Glass nowadays has different types and categories. In this paper, the thermal performance characteristics and techniques to reduce the heat gain from the glass is discussed.

Gathering and plotting the external data can provide a guideline for designers to choose the most Energy efficient and proper façade system type according to building design criteria. Looking at each medium or large city it is easy to realize how many of new modern building area are covered with a glazing. In literature, examples of unsuccessful glazed buildings are very easy to find.

Complementing the emerging technologies of the envelope construction with day lighting strategies is not of significant importance in achieving energy efficiency. The pattern of energy usage by electrical appliances are distinctly different in residential and commercial buildings. BEE's assessment indicates that lighting and air conditioning uses 80 percent of energy in commercial buildings whereas, fans and refrigerators use maximum energy in residential buildings. Usage of appliances is additionally more varied in residential units that are mostly lifestyle and selection related (Fig.1).

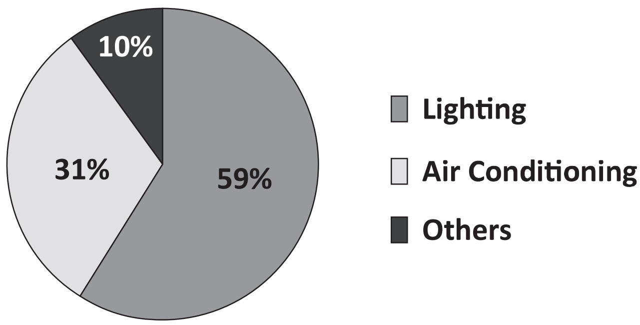

Fig. 1 : End use of commercial buildings Energy consumption
(Source : Bureau of Energy Efficiency, 2019)

2. Methodology :

This chapter explains about the research methodology used in this research. The research methodology is a useful and easy technique, as new ideas and theories can be built. The methodology follows the following steps (Fig. 2).

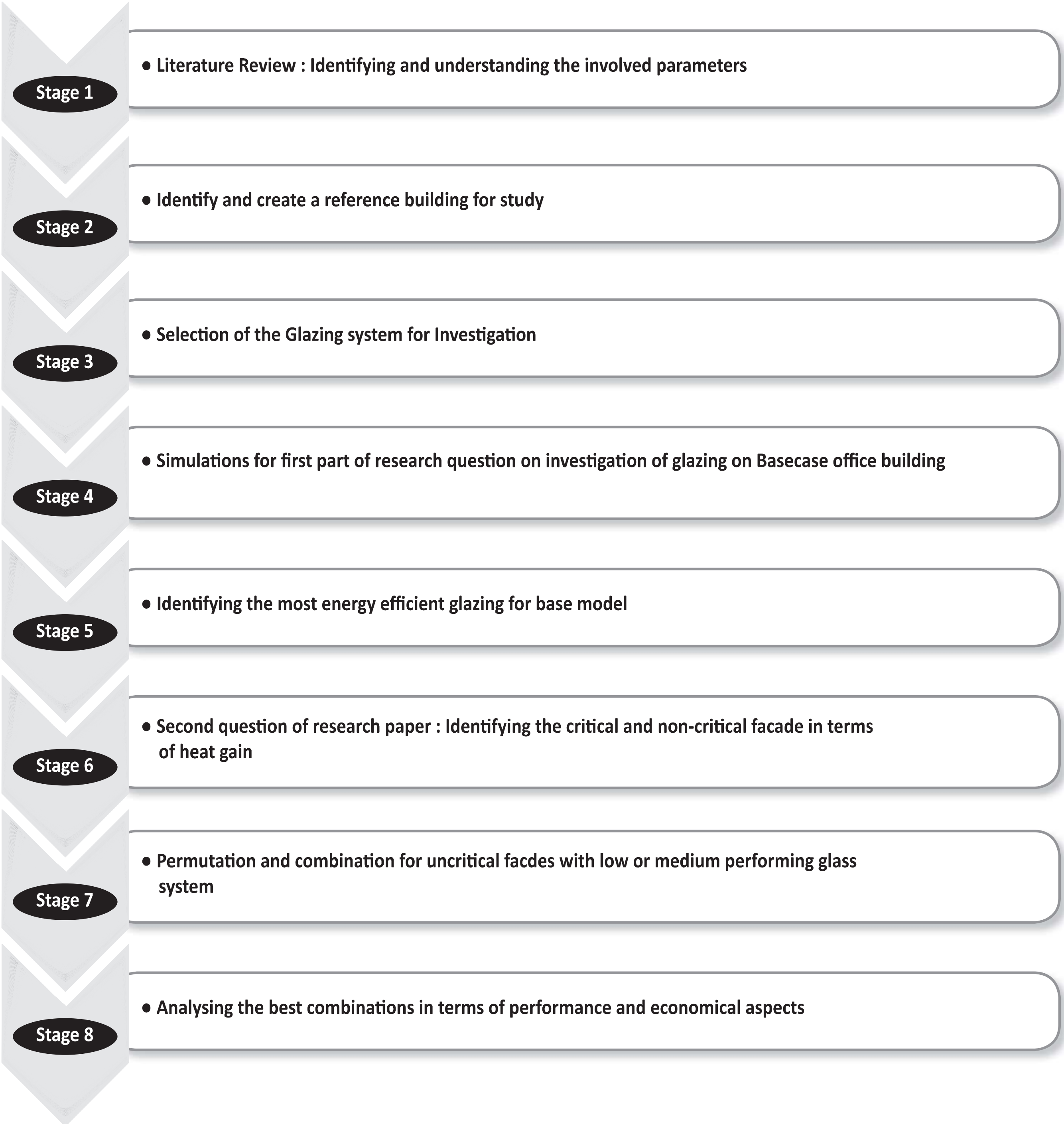

Fig. 2 : Flow chart for the research methodology

2.1. Building Data :

The study model is a hypothetical office building located in Pune, India. It has warm and humid climate type. It's orientation is N-S or W-E as the Building is square in shape i.e; 45m x 45m (2025 sq.m). All the floor plate are identical in area and shape (Fig.3) . Total ground coverage area is 2,025 sq.m. Total built-up area is

16,200 sq.m. Total Air-conditioned area in building is 14,400 sq.m. The service area is 15m x 15m located in the centre of the Office building. Total height of the building is 28m and height of each floor is 3.6 m. The WWR for all four façade is taken as 95% i.e; the only 5% of the building has the opaque façade. Some considerations are made regarding building is that, the wall material which is transparent is single clear 6mm thick glass, and the opaque material in vertical façade outside the building is cement bricks. The material of the roof is 130 mm thick flat concrete slab. It is assumed that the building is fully air conditioned throughout the working hours i.e; 9am to 9pm. The building does not have any shading devices in it. The building has air cooled chillers, the lighting limit is mentioned for office working area is min. 300 lux and for service area it is 120 lux.

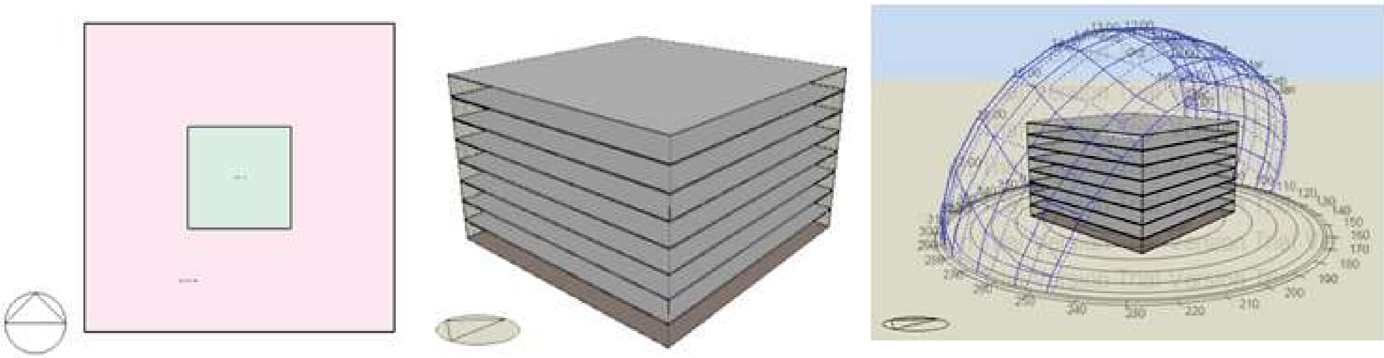

Fig. 3 : (a) Typical floor Plan, (b) Building View, (c) Building view with sunpath diagram (Model extracted from Design Builder software)

2.2. Classification of Climate in Pune:

Warm and humid climate is characterised by discomfort caused to people by heat and its associated temperature which doesn't fluctuate. The temperature during day is between 27 – 32 degree Celsius whereas at night it is between 21-27 degree Celsius . Humidity is high ranging from 70-90%. The intensity of radiation is high during summers and moderate during winters. High humidity, strong sun, glare from the sky characterises this climate. So, the major objective is resisting the heat gain by the building.

2.3. Energy Efficiency Aspects :

Nowadays, energy performance of the building is a key factor while designing the façade, as energy saving is the need of hour. Therefore, various techniques are used to make the façade energy efficient. The use of solar control and low E coating is very popular in designing an Energy efficient façades. Glass selection should allow maximum daylight to come inside the building to reduce use of artificial light inside with appropriate control solar heat gain. North glazing allows natural day lighting in southern hemisphere with minium solar heat gain.

2.4. Factors to be considered in Glass Selection :

2.4.1. U-factor and U-value :

These are interchangeable terms pertaining to a measure of the warmth gain or loss through glass due to the difference between indoor and outdoor air temperatures. It is denoted as Watts per square metre Kelvin W/m2 K. Lower the U-value the higher the thermal performance of the glass.

2.4.2. Visible light transmittance (VLT):

It is an amount of visible light that drives through a glazing material. It is determined by the glass colour and thickness. A higher VLT indicates more daylight in a space which, if designed properly, can compensate electric lighting and its associated cooling loads.

2.4.3. Solar Heat Gain Coefficient (SHGC) :

It is the part of solar radiation admitted through a window, door, or skylight either transmitted directly andabsorbed, and subsequently released as heat inside a home. It's measured between 0 and 1; a lower number indicates less solar heat transfer.

2.5. Type of Glazing Investigated :

The glazing systems can be broadly categorized in different types due to its changing properties which are selected below. The thermal and optical properties are compiled in Table 1.

2.5.1. Single Clear Glass:

It comprises of a single pane of glass available in different thicknesses.

2.5.2. Insulating Glass Units:

These glazing system consists of two or three panes of glasses isolated by an air gap to regulate heat transfer through conduction [1].

2.5.3. Glazing filled with Inert Gas:

Gas other than air such as Argon or Krypton is used in the form of insulation to stop conduction and convection behaviour between the glass panes [1].

2.5.4. Electrochromic Glazing:

These products work similar to Liquid Crystal Devices. However, it permits the user to vary the amount of current through the device to vary the degree of tint in the window [1]. It also utilizes a small electrical voltage to adjust the shading coefficient and visible light transmission.

2.5.5. Reflective Glazing Systems:

It has a mirror-like emergence due to which it reflects and absorbs a major portion of sun's direct short wave solar radiation. The degree of reflectivity relies on the type of coating and orientation of the glass [1].

2.5.6. Spectrally Selective Systems:

These products typically consists of films, tints, or coatings; which reflect selected wavelengths of light, while permitting others to pass through. There is an immense range of performance qualities that can be achieved using these products [1]:

a. Tinted glass contains minerals that colour the glass evenly through its thickness and promote absorption of visible light and infrared radiation.
b. Coatings: These products are aesthetically appealing and are applied directly to the glazing, to control solar heat gain by limiting those wavelengths of light that are allowed to pass through and are reflected. These products are commonly referred to as Low-E coatings.

2.6. Energy Simulation of Building :

In this study, the energy simulations are performed to estimate the annual energy consumption and there cost by different assemblies of glazing system. The methodology is predicated on the study of energy problem. The impact of various glazed system on the study model is calculated through simulations. The model is simulated within the Design Builder V6 Software. The building simulation is run for various glazed façade system to work out the simplest one to optimize the space cooling load on the HVAC system. All the interior spaces within the building were modelled together thermal zone, that maintain uniform indoor temperature and humidity. The performed analysis are based upon simulation tool result, therefore the results are only accurate if all variables match those of the simulation inputs. For the glazing selection process, the integrated comparative analysis are indeed a useful deciding tool. In simulation all the variables are constant accept the glazing specification like U-factor, SHGC, VLT, Direct light transmittance. The schedule of the building is of 12 hrs.

Energy and economical comparison are wiped out, in order to use the integrated assessment process. Glazing types chosen for the study model consists of a good range of glazing technology within the study from low to high performance (Table 1).

High level of detail doesn't affect the ultimate result because the major energy consumption is by Air-conditioners. Several high performance window design strategies are available within the market today to maximise efficiency while maintaining visual characteristics. Glass façade energy efficiency depends on its framing, glass, and operation. And since glazing technologies are often combined there are many types available [2-4].

Table 1. Thermal and optical properties of investigated glazing systems

Sr. No.	Thermal and Optical Properties of Glasses for Investigation	U-Value W/m2-k	SHGC	VLT
1	Single clear 6mm thick Glass	5.778	0.819	0.881
2	Double Reflective Clear 6mm/13mm Air	2.216	0.137	0.073
3	Triple Clear 3mm/13mm Air	1.757	0.684	0.738
4	Triple Low-E (e2=e5=1)clear 3mm/6mm Air	1.573	0.472	0.661
5	Triple Low-E (e2=e5=1)clear 3mm/13mm Argon	0.780	0.474	0.661
6	Double Reflective clear 6mm/13mm Argon	2.109	0.179	0.120
7	Double Reflective tint 6mm/13mm Air	2.301	0.167	0.081
8	Double Reflective tint 6mm/13mm Argon	2.109	0.159	0.081
9	Double electrochromicabsorbtive coloured 6mm/6mm Air	2.429	0.197	0.114
10	Double electrochromicabsorbtive coloured 6mm/13mm Air	1.761	0.168	0.114
11	Double electrochromicabsorbtive coloured 6mm/13mm Argon	1.493	0.157	0.114
12	Double electrochromic reflective coloured 6mm/13mm Air	1.761	0.155	0.137
13	Double electrochromic reflective coloured 6mm/13mm Argon	1.493	0.144	0.137
14	Thermochromic glazing	2.130	0.569	0.578
15	Double reflective clean 6mm/6mm Air	2.761	0.154	0.072

3. Results & Discussions :

The total energy consumption of the basecase model shown in (Fig. 3) is simulated through the design builder software. Out of the total energy consumption of the basecase building, the 87 % is consumed by HVAC system, 5 % is consumed by lighting system and 8 % is consumed by other equipment. Based on the outcomes, the significant energy use percentage is contributed by cooling system for buildings in warm and humid climate. The maximum the building gains heat, the maximum energy it consumes to cool it.

Solar heat gain can be significantly reduced by using the proper type of glazing for the façade. The research is performed in two steps, first was to find the most energy efficient glass façade for an office building in warm and humid climate of India. Different types of glazing systems are selected and then simulated for the basecase in design builder from there the energy reduction is found out for each glass system selected.

The glass assemblies selected are single, double, triple layer filled with air, argon, gases or reflective, tinted and etc. The highest impact on buildings energy efficiency is done by glazing properties that is SHGC and VLT. It is an evidence that the solar gain are the most critical variable in glazing system (Fig. 4).

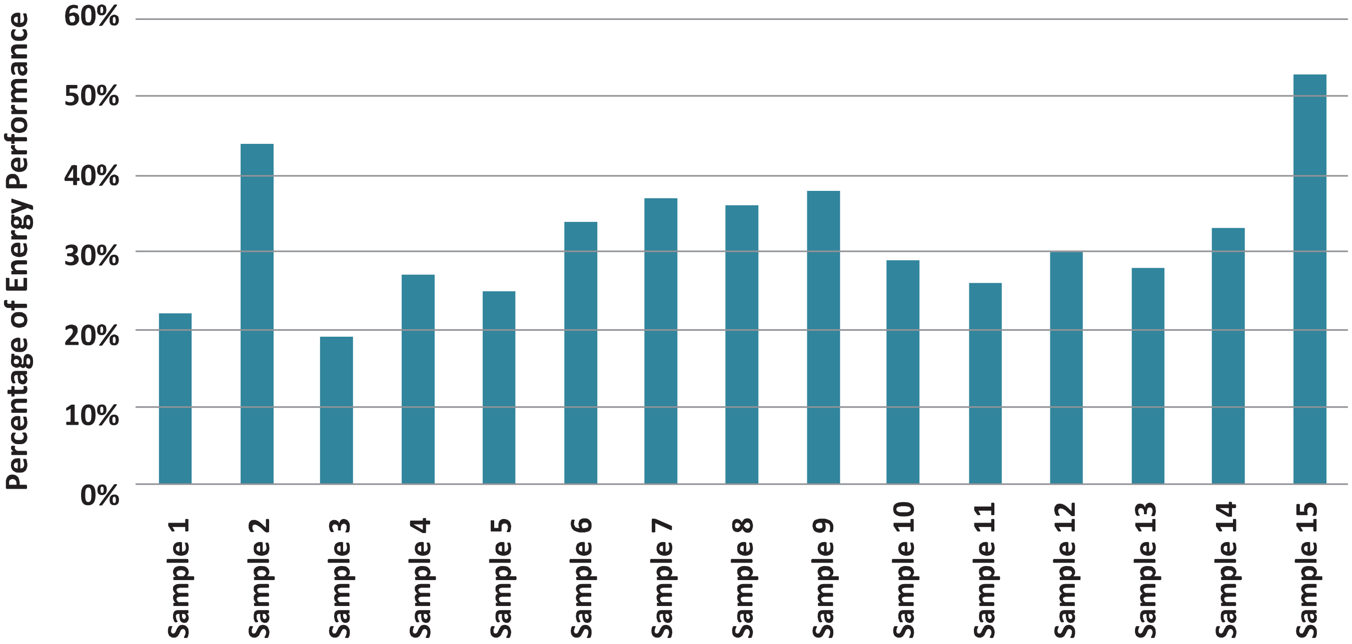

Fig. 4. Comparative analysis of energy performance by different glazing selected for Investigation

In this section, simulation results will be indicated and discussed for the considerable data was generated from Design builder software output. The simulation data is collected and compared with the basecase energy consumption. The single clear 6mm thick glass is considered to be the basecase for comparative study as it is the lowest performing glass assembly. From the simulation results of different glass types, the overall observation is made that the Double Reflective clear glazing with 13mm air gap is better than the double reflective with 13mm argon filled glass. Whereas, double reflective tint glass with 13mm air filled is better than 13mm argon filled then the double tint with 13mm argon filled glazing.

The best performance out of the four double electrochromic glazing system types is of Double electrochromic reflective coloured 6mm/13mm argon. From the Design Builder simulation results of different glass assemblies energy efficiency is checked and analysed that the most energy efficient glazing system is the Type 15th i.e. Double reflective A-L clear 6mm/6mm air filled glass for warm and humid climate. The thermal performance of double-glazed or triple-glazed windows can be further improved by the addition of a low-emissivity coating on one or all of the layers of glass. The air space also reduces heat gain and loss transmission, which gives the insulating glass superior thermal performance compared to single glazing [5-7].

But as the quality or energy performance of glass increases the cost also increases parallelly. In this paper the second part of research was to find an economical solution for fully glazedoffice building. So, the study was performed to identify the critical façade in terms of heat gain in warm and humid climate. For finding the critical façade, the sunpath diagram of Pune (fig. 5) and also cross checked for the basecase model through simulations. The most critical facades was observed to be South and west both. So, providing the South and west façade with the most energy efficient glazing assembly i.e; The façade which doesn't lead to heat gain are observed to be North and East, as the movement of the sun is from east to west towardsthe South side. So, the north façade stays away from the direct sun and heat gain whereas, the east façade faces the morning sun which has less intense heat.The uncritical facades doesn't require a high performing glass system as south and west does. Now, finding the economical solution for North and east façade, some permutation and combinations of glasses are selectedwith low or medium performance are simulated in the basecase (Table 2).

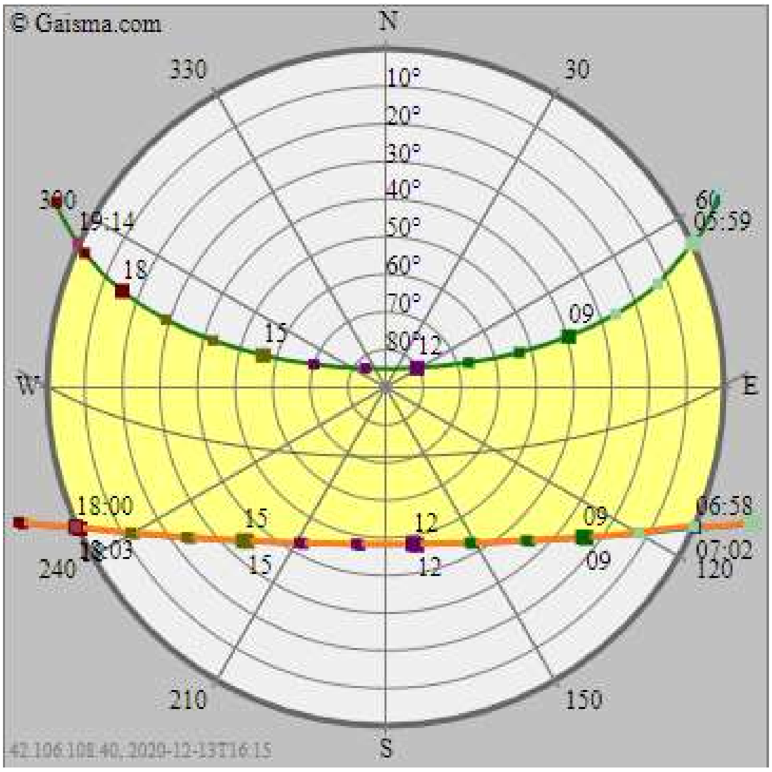

Fig 5 : Sunpath Diagram of Pun (source: Gaisa.com)

Table 2. Permutation and Combinations performed for North and East façade for basecase office building

Sr. No.	Permutation & Combination of different Glass Types	Glass System Types	Variable Cardinal Direction
1	CASE 01	Sample 1	N
		Sample 1	E
2	CASE 02	Sample 2	N
		Sample 2	E
3	CASE 03	Sample 7	N
		Sample 7	E
4	CASE 04	Sample 6	N
		Sample 7	E
5	CASE 05	Sample 7	N
		Sample 8	E
6	CASE 06	Sample 1	N
		Sample 7	E
7	CASE 07	Sample 7	N
		Sample 2	E
8	CASE 08	Sample 6	N
		Sample 2	E
9	CASE 09	Sample 8	N
		Sample 2	E
10	CASE 10	Sample 1	N
		Sample 2	E

The permutation and combination results are performed in Design builder software (fig. 6). The five low performance glass assemblies were selected. So, total ten case are performed out of which it can be observed that the 10th case performs better, i.e; North performs better with the base case that is single glass and East performs better with the double reflective clear glass sandwiched with air which gives efficient results in terms of energy and cost.

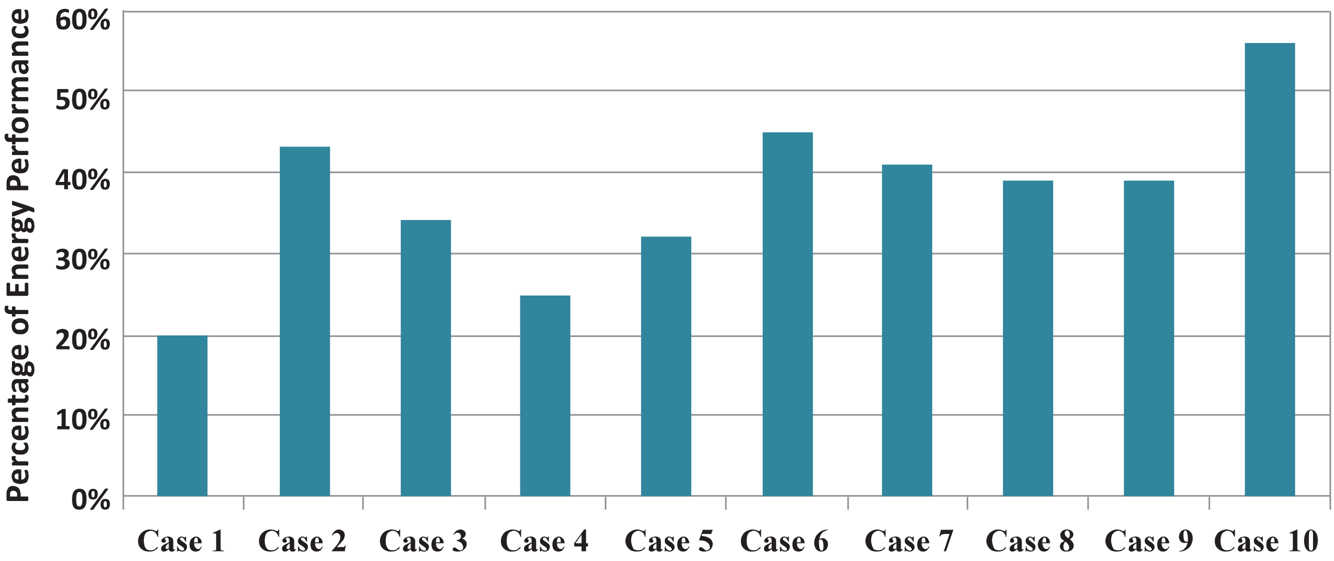

Fig. 6. Comparative analysis of energy performance by different glazing selected for investigation for north and east façade for achieving economical glazing solution

4. Conclusion :

The paper studied the characteristics and effect of different glazing systems on the annual energy consumption in warm and humid climate to provide an energy efficient and economical solution for fully glazed office building façade through Design Builder simulations. This analysis involved the comparison of the effect of various selected glazing systems.

It is analysed that the SHGC and U-value of glazing system have a remarkable impact on the energy performance of building. Low SHGC and U-value glazing are vital parameters to consider while choosing the glazing type for warm and humid climates.

i. Electrochromic glazing system is one of the smart technology, which can reduce the direct solar heat gain by the glazed facade. Results show that the performance of the investigated glazing system vary and the best glazing performance are those with the insulating properties like double or triple layered glasses as compared to single glazing.

ii. The width of rift in middle of the glass panes and the type of gas filled in effects the performance of building. Out of all filler in between glass, the air filled glasses shows the better performance than argon or gases in warm and humid climate.

iii.The second part of the study was to provide the economical solution for the glazed façade for an office building. A detailed study on the different facade of building is worked on, so as to provide a fully glazed building with an economical solution. And avoiding the unnecessary need of high performance glazing system for all sides of façade of a building.

The basecase building is symmetrical in plan. Through the number of simulation it is observed that the most critical façade in terms of direct heat exposure is South and west façade, whereas the east facade faces the morning sun which has less intense heat. And the North façade does not face the sun directly as, the movement of sun is from south side. So for finding the economical solution, the number of permutation and combination of simulation was run and the result was found that the most critical façade i.e; South and west needs the best performing glazing system from the above table whereas, North façade can also perform better with the basecase glass sample 1, that is single clear 6mm thick glass. And East performs better with double reflective A-L clear 6mm/6mm air filled glazing.

The conclusion obtained in this research applies only to the building model characteristic under analysis. Similar assessment to other building type and climate can be applied with caution. The use of detailed computer simulation is recommended to define the influence of the architecture decision in the energy efficiency of the building.

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