ENERGY EFFICIENT GLASS BUILDINGS IN HOT & DRY CLIMATE

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Abstract*:* Glass has been a desirable material to mankind since it had been first made in about 500 BC. It is one of the foremost versatile and oldest materials within the building industry. Nowadays the number of clients who prefer glass is increasing, due to advantages like glass transmits up to 80% of obtainable natural daylight, the glossy appearance and is weather resistant and can withstand various factors like sun, wind, rain, along with rust due to chemical or environmental effects, etc. by retaining its appearance and integrity at the same time. The drawback of glass is that it has huge transparency of heat which can be balanced with a relatively low R-value. Glass absorbs heat and can act as a greenhouse hence is not suitable for hot climates. In modern times an office building is characterized to be a transparent building. A glazed façade has a lot of effects in terms of energy impact, like increased operational cost due to high solar heat gain. However, the paper aims at designing glass buildings in hot climates to increase energy efficiency by identifying the optimal parameters for the envelope. Attention is to be given to the choice of glass and the double-skin façade system which would help in terms of daylight, reduction in sound and energy consumption, also increasing the occupant comfort.

Key Words*:* Glass Buildings, Easy Maintenance, Environmental effects, Double Skin Facades, Appropriate choice of glass

1. INTRODUCTION

Glass is one of the dominating materials of modern-day architecture. It has earned its position due to its versatility of being used in windows, doors, envelopes, internal partitions, etc. In the present, this magical material also possesses various technical features that can cut the heat, solar, sound, safety, etc. The main aim of these features is to cut down the energy consumption especially in this challenging time of increasing prices of energy and raw materials. Passive design strategies should always be a designer's first option to make the building more energy efficient before opting for more advanced building systems. The research paper deals with how glass building can be designed by maximizing the use of technicalities of glass and optimizing the envelope further by using double-skin facades.

Fig 1 : Examples of Glass Façade buildings

2. CHARECTERISTICS OF HOT & DRY CLIMATE

In India this type of climate can be experienced in Rajasthan, Gujarat, Maharashtra and some parts of Madhya Pradesh and Karnataka also.

2.1. TEMPERATURE: The temperature of such areas is usually very hot and can go up to or more than 50oC in summers. A high-temperature difference between the day and night temperature is also a characteristic of such areas. (15 to 20 degree Celsius)

2.2. HUMIDITY: These areas receive very hot and harsh sun rays leading the humidity to be very low which generally varies between 10 to 50%.

2.3. PRECIPITATION: As discussed the air in such areas is very hot and dry as these areas have very low precipitation. The precipitation is as low as 50 to 150 mm per year.

2.4. SKY CONDITIONS: These areas usually have a clear and blue sky but sometimes there are incidences when the sky is filled with dust storms and unbearable glare is created due to these dusty skies.

2.5. SOLAR RADIATIONS: Due to the above mentioned clear sky condition; the solar radiations are direct and strong during the day time and often escape into open clear skies during nights.

2.6. WIND: The high speedy and dusty winds are also a common feature of these types of climate. The wind speed usually varies between 20 to 30 kilometers per hour. It is often observed that the wind changes its direction locally.

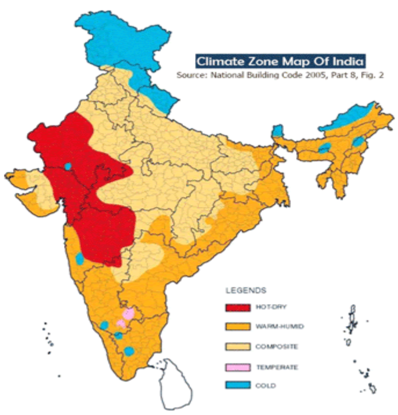

Fig 2: Climatic Zone Map of India

3. FAÇADE AS AN INSEPARABLE COMPONENT OF THE BUILDING

The façade of a building plays an important role as it not just makes the building aesthetically appealing but also plays a huge role in the energy optimization of the building. It is the main link between the exterior environment and the interiors. The innovative materials, ideas, and designs in the building façade can unlock a multitude of energy-efficient opportunities in the building. A façade is a primary element that communicates the values of the company and organization to the clients. It is also important to study how facades react to the natural and man-made environment which should be balanced with cost and engineering constraints.

3.1 PARAMETERS AFFECTING FAÇADE DESIGN

The parameters that affect façade design are as follows (1)

a) **HARD COST:** Façade construction, Mechanical system, and Building structure
b) **SOFT COST:** Energy, operation, and maintenance
c) **ECOLOGICAL IMPACTS:** Source of materials, the potential of material re-use, carbon equivalent
d) **HUMAN IMPACTS:** Thermal comfort, light quality, acoustic benefits, fresh air, etc.

4. CONSIDERATIONS IN GLASS FAÇADE BUILDINGS

Glass buildings can act as a greenhouse and hence to avoid this greenhouse effect buildings opt for air conditioning but unfortunately cooling the building adds more to carbon emissions. Façade is one of the main constituents of a building between the internal and external environment and also plays a crucial role in energy optimization and the comfort of occupants within the building. Reduction of energy consumption is possible if the facade is well planned at the design stage itself with proper selection of glass and various architectural features.

4.1. ASPECTS OF GLASS FACADES (1)

4.1.A. FUNCTIONAL FITNESS: Glazing plays an important role in connecting the external and internal environment of the building. It also increases the aesthetic value of the room and also creates a depth in the room with the proper play of light and shadow. It welcomes a lot of daylight in the room and daylight is an important source of health for human bodies. Functional fitness of glass includes various parameters like size, weight, placement of mullions, constructability, etc. Factors like sun path, daylight analysis, thermal analysis, etc. play an important role in selecting the glass type for the façade.

4.1.B. STRUCTURAL ASPECTS: It is very important for the glass façade to be structurally fit and tolerant to various loads encountered by it. Structural analysis of the glass will help us to decide the thickness of glass, whether to use it as a single glass unit or double glass unit etc. This wind load can be studied either by a wind tunnel report, wind simulation, or wind load calculations as followed by most of the cases today

4.1.C. ENERGY-EFFICIENCY ASPECTS: Energy-efficient façade is also one of the key factors in modern architecture. For designing an energy-efficient façade various factors come into the picture like the orientation of the building, architectural features to block direct sunlight, louvers, etc. these features help to ensure that solar gain is minimal in the building at the design stage itself and helps to reduce the cooling demand in the building. Using Low E glass and solar control is getting very popular in recent times for designing an energy-efficient facade.

4.2. CHOICE OF GLASS FOR FACADES

Glass facades are one of the style quotients for modern architecture. It is so much into use that it is difficult to imagine a contemporary building without slight usage of glass. Nowadays glass not only satisfies the aesthetical requirements but also the technical and functional requirements and hence is no more a filler material but an important component of construction. To choose the best glass for the project, the real need of the project needs to be understood. Glass selection for façade should be done carefully to make the building more energy-efficient. A good choice of glass will maximize the light entering the space as well as provide optimal insulation. Thus in addition to size, colour, safety, and comfort-related factors such as thermal insulation, glare, sound insulation, etc. also play an important role in the choice of glass made.

4.3. FACTORS TO BE CONSIDERED IN GLASS SELECTION

4.3.A. SHGC (SOLAR HEAT GAIN COEFFICIENT)/ SF (SOLAR FACTOR): The SHGC is the fraction of incident solar radiation admitted through a window, both directly transmitted and absorbed and subsequently released inward

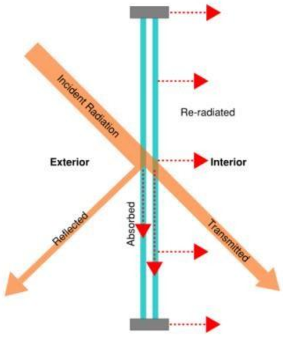

Fig 3: Solar Heat Gain Factor

4.3.B. U VALUE (W/M2 K): Thermal transmittance is the rate of transfer of heat through matter. The thermal transmittance of a material or an assembly is expressed as a U-value. The lower the U value the better the material

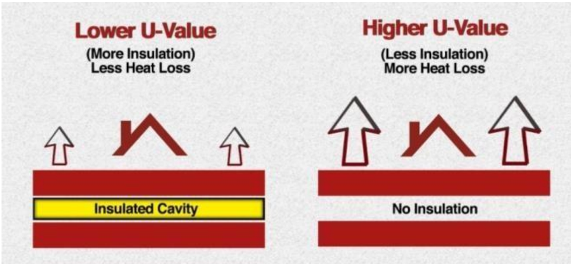

Fig 4: U value

4.3.C. RHG (RELATIVE HEAT GAIN): The amount of heat gain through a glass product taking into consideration the effects of solar heat gain (shading coefficient) and conductive heat gain (U-value). The lower the RHG, the greater the glass restricts heat gain.

4.3.D. ULTRAVIOLET TRANSMITTANCE: The percentage of incident ultraviolet energy that is directly transmitted through the glass. Clear glass allows upto 72% and tinted glass around 40% of UV to pass through, depending on its thickness.

4.3.E. SOUND TRANSMISSION: The sound attenuation of any material depends on its mass, stiffness, and damping characteristics. The sound transmission loss for a single glass pane, measured over a range of frequencies, varies depends on glass thickness. Thicker glass tends to provide greater sound reduction even though it may transmit more sound at specific frequencies.

4.3.F. VISIBLE LIGHT TRANSMITTANCE (VLT): It describes the percentage of visible light transmitted through the glass. It is determined by the glass colour and thickness. Clear float glass has 75% to 92% VLT; coloured glass has 14% to 85% VLT

Fig 5: Comparison of glasses with different VLTs

5. HEAT ABSORBING GLASSES:

The incident radiation is partly absorbed and partly reflected when struck on an opaque surface:

$$a + r = 1,$$

In-case of transparent surfaces, the incident radiation may be absorbed, reflected or transmitted. This can be expressed in a form of an equation by the co-efficient transmittance (t) as:

$$a + r + t = 1$$

An ordinary window glass usually transmits a large proportion of the radiation incident on it between 300 and 3000nm i.e. both visible light and short wave infra-red, but very little around and outside the 300 to 3000nm range. Here, the transmittance is selective and this selective transmittance can be modified by varying the composition of glass to reduce substantially the infrared transmission, while only slightly affecting the light transmission. Such a product is referred to as heat absorbing glass.(4)

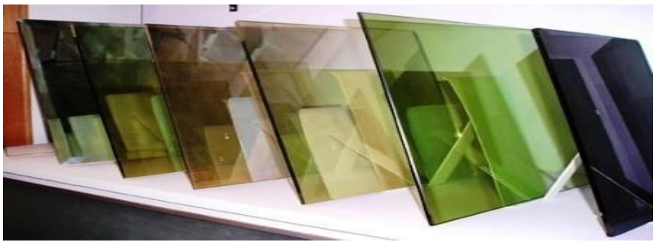

Fig 6: Tints of heat absorbing glass

Special tint heat-absorbing windows absorb as much as 45% of incoming solar energy, this helps to reduce the heat gain in an interior space. Tinted glass reduces the solar heat gain coefficient (SHGC), visible transmittance (VT) as well as glare. Part of this absorbed heat continues to be passing through the window by conduction and re-radiation, which means that the tint doesn't lower a window's U-value but these types of heat transfer can be reduced by applying selective coatings on the inner layers which would help the glass to act as insulated glazing.
The grey- and bronze-tinted windows which are most commonly used are not spectrally selective but have properties to reduce the penetration of both light and heat. Blue- and green-tinted windows offer greater penetration of visible light and also slightly reduced heat transfer compared with other coloured tinted glass. In hot climates, the black-tinted glass should be avoided under any circumstance because it absorbs more heat than light. As tinted, heat-absorbing glass reflects only a small percentage of light, it does not have the mirror-like appearance of reflective glass. This glass reduces solar heat while maintaining visible light transmission at the same time. The soda-lime glass which is light blue/green in colour subdues brightness while providing high visible light transmittance of up to 77% for a glass that is 6.0mm thick. The U value of these types of glass ranges around 1.9 $W/m^{2.}$

6. TYPES OF GLAZING:

6. TYPES OF GLAZING: Experts say that almost 10% of heat gain in the building is due to inappropriate choice of glazing.(2) The thermal performance of these glazing is determined by the U value. There are majorly three types of glazing which are as follows:

6.1. SINGLE GLAZING: It is the most basic form of glass with a single pane of glass. It is used in most of the older buildings. In single glazing, conduction occurs quickly as there is just one layer of glass between the interior and the exterior environment allowing energy to escape more rapidly. It is the cheapest of all types but having the least preferred U value around 4.4 W/m^2

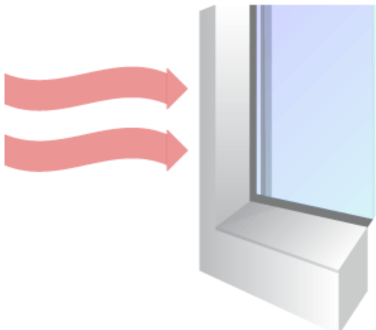

Fig 7: Single Glazing

6.2. DOUBLE GLAZING: Double glazing has two panes of glasses separated by a space bar. This gap traps the heat and slows its entry into space. The space between the two panes is either filled with air which has insulating properties of even inert gases such as argon for better performance. It has good thermal and acoustical properties as well. It has an average U value of around 2.2 W/m^2.

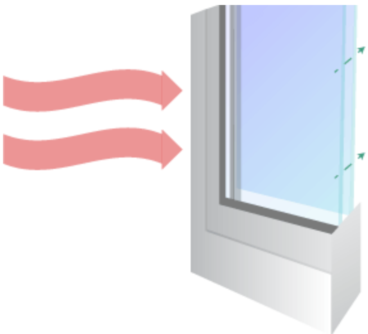

Fig 8: Double Glazing

6.3. TRIPLE GLAZING: It is one of the most thermal efficient glazings which is very much similar to double glazing but provides exceptional levels of thermal and acoustical insulation. It has the same concept as that of double glazing with three panes of glass which is separated by space bars filled with air or inert gases which traps the heat and further slows down the heat transfer to space. It can massively reduce the cooling load of the building if installed properly but is the most costly of all glazing types. It is considered to be a great insulator with an average U value of 1.1 W/m^2

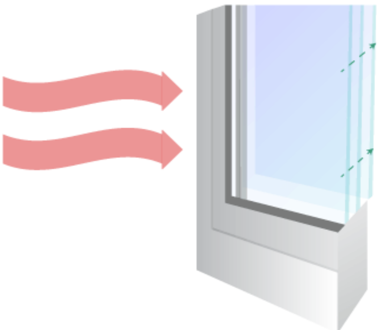

Fig 9: Triple Glazing

7. WALL WINDOW RATIO

Recently the inclusion of daylight in office buildings has gained a lot of importance. The use of natural light will reduce the dependence on artificial lights thus reducing the energy needs. A building's energy performance is also directly dependent on the window area or the window-to-wall ratio (WWR). As the higher percentage of window area will lead to heating of the building thus leading to an increase in the cooling demand of the building. At the same time, the natural environment in terms to access to daylight, view, and ventilation is also dependent on the window area. The window-to-wall ratio is the ratio of the total fenestration area to its exterior envelope wall area.(5)

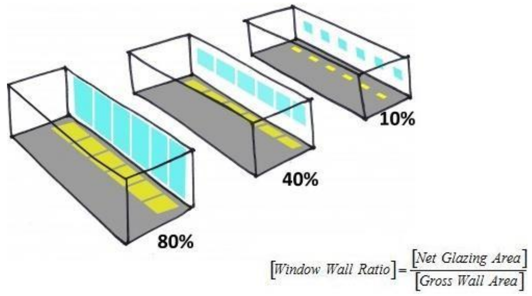

Fig 10: Sample of Wall window ratio

From Standard requirement for WWR (ASHRAE 90.1-2007)

WWR	x<0.24	0.24	>0.30
Value	Poor	Good	Overheat

Table 1: Standard WWR and its effect on the building

Nowadays facades are designed with a higher percentage than the prescriptive code with the help of high-performance glasses or in the combination of internal and external shading devices and strategies including intelligent facades.

8. CONTROL OF SOLAR RADIATION THROUGH SHADING

Exterior shading for a building is important as it controls the direct penetration of the sun into the habitable spaces thus heating the space. These shading devices can be directly attached to the building or can form a part of the building design by extruding the floors to create overhangs at intervals. (6)

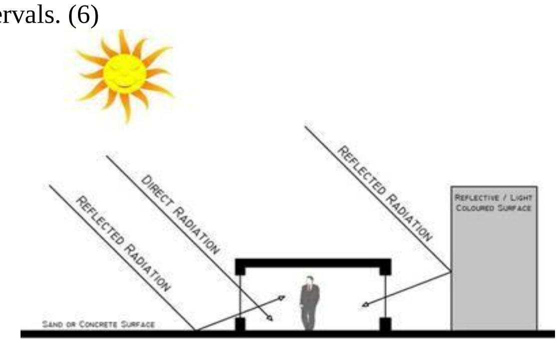

Fig 11: Sources of Solar Radiation that May Require Shading

Exterior shading devices are always preferred over interior shading devices as it helps to block the direct solar radiation to enter the space. The traditional interior shading devices include blinds or curtains, but they just block the glare from the sun allowing the heat to enter the interior space.

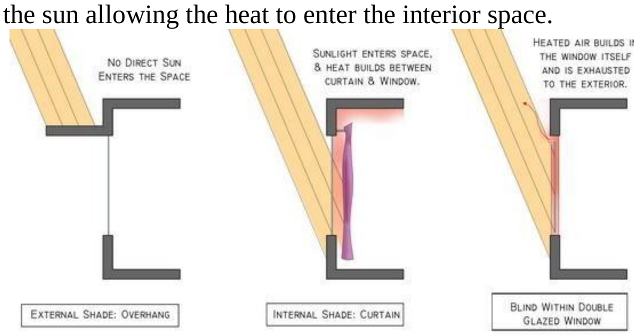

Fig 12: Benefits/Detriments of Shading Locations and Types

8.1. DIFFERENT FAÇADE TREATMENT FOR EACH ORIENTATION

The important aspect of shading is that solar exposure for each façade is different for different orientations due to the position of the sun. Due to this reason, each façade has to be treated with a different approach. Usually in the northern hemisphere, except for the summer months early morning and late evening, no sun penetration occurs. It is advised to limit the shading devices on the north as this façade will have the least heat gain.

The southern façade of the northern hemisphere is the easiest façade to control solar energy. As the sun is vertically above, the shading devices are designed horizontally to cut the direct solar heat gain. However, these shading devices are designed as per the height of the window and the angle of elevation of the sun. The best way to design a horizontal projection for a fenestration is by blocking the summer sun and letting the winter sun into space.

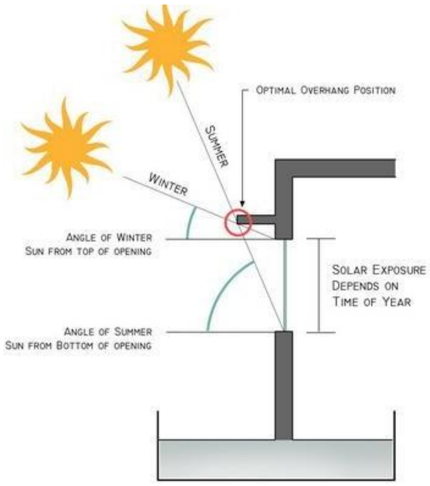

Fig 13: Basic Shading Strategy for a South Elevation

Architecturally, the east and west facades are the most difficult to shade as the morning and evening sun is at such a low angle that it is difficult to prevent the sun from entering the space with the help of horizontal projections. The heat and unbearable glare of the evening sun are much harsh as compared to the cooler and less offensive morning sun.

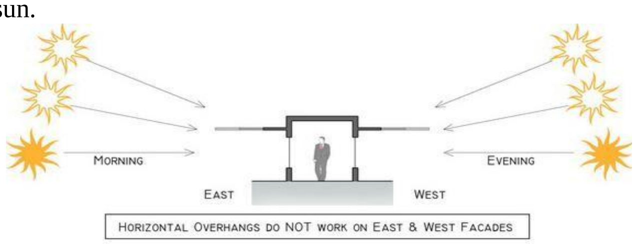

Fig 14: Shading Issues with East and West Facades

9. DOUBLE SKIN FACADES IN HOT & ARID CLIMATES

Double skin façade is a technology that is of great use in hot and arid climates as it improves the design, overall performance, and operation characteristics. The depth of the cavity is one of the primary factors that control the rate of ventilation and the heat trapped within the double-skin façade system. According to various studies conducted the optimum cavity depth ranges from 1000-1200mm. Hence a cavity depth of a minimum of 1000mm opts for hot climates high-rise office buildings. The main aim of a double skin façade is to design an energy-efficient building without the compromise of glass usage.

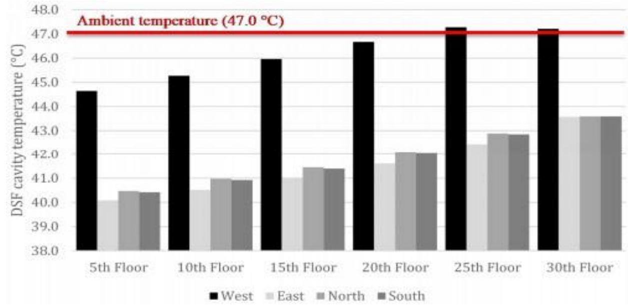

Fig 15: Sample simulation results showing average cavity temperature for each orientation and floor

The cavity in the double skin façade has varying temperatures depending on the orientation. The DSF on the west façade is seen to have the highest temperature with the least performance as compared with other orientations. With a deep penetration of light through the envelope and control of cooling load of the building somewhere makes double-skin façade a green technology.

9.1. CONSTRUCTION OF DOUBLE SKIN FAÇADE

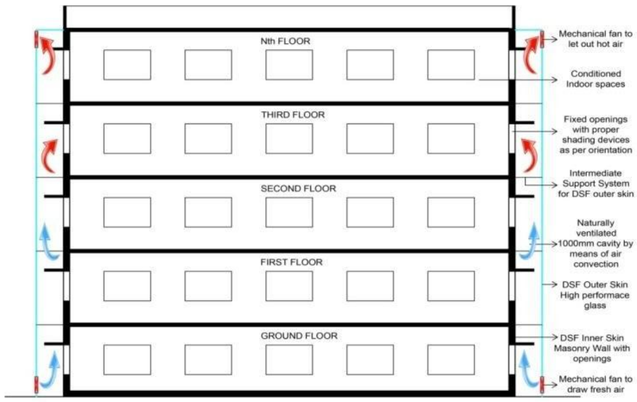

Fig 16: Cross section of a sample DSF

Double skin facades have two layers of an envelope with an intermediate cavity for air to flow. This air cavity can be naturally ventilated, or a fan to support air circulation, or a mechanically driven ventilation flap to avoid overheating or condensation in the cavity. The curtain walls have improved a lot due to the advancements made on frames, fillings, and sealants. Improvement in technology has resulted in dimensions, durability, and anchoring techniques making the construction lighter and increasing the element size up to 3.2 x 15 m. Nowadays, the production of bigger pane sizes, client-specific geometries, combinations of multilayer laminated safety glass or insulation glass, and glass setups with different functional coatings is possible due to the latest fabrication technology. (6)

9.2. MODES OF VENTILATION IN THE CAVITY

The beginning and the destination of the airflow is referred to about the modes of ventilation. It can be done naturally, mechanically or even hybrid which involves both natural as well as mechanical.(3)

Mode of ventilation in cavity	Air flow	Figure No.
Outdoor Air Curtain	Air comes from the outside and evacuated toward outside	Fig 3 & Fig 4
Indoor Air curtain	Air comes from the inside of the room and returned to the inside of the room, naturally or mechanically	Fig 1 & Fig 2
Air supply	The outdoor air flows to inside of the room or into the ventilation system	Fig 6 & Fig 8
Air exhaust	Air comes from the inside of the room and is rejected to the outside	Fig 5 & Fig 7
Open	Air can come from both outside and inside (no ventilation in cavity)	Fig 9
Close	Cavity forms a buffer zone between the inside and the outside, and no ventilation in cavity is possible	Fig 10

Table 2: Types of modes of ventilation in the cavity

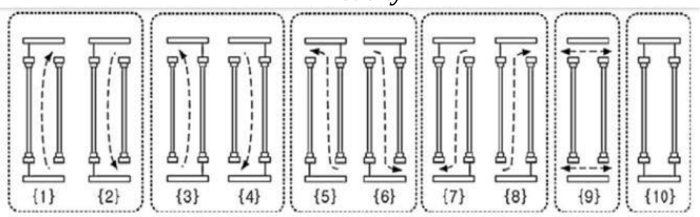

Fig 17: Airflow regimes in cavity

9.3. DSF PERFORMANCE

As per past experiences, most of the designers believe that double-skin facades have a better performance in terms of natural daylight, thermal insulation, sound reduction, and reduction in the cooling load of the building.(8)

9.3.A) NATURAL VENTILATION & THERMAL INSULATION: The space between the two skins can help to protect the inner spaces from harsh climates and help to maintain the comfort level within the building. This could be gained by closed, protected, or screened opening on the inner skin. A ventilated cavity space is proven to have much better thermal insulation in both hot as well as cold climates.

9.3.B) DAYLIGHT: Daylight is one of the primary requirements to make the building energy-efficient. The difference between single skin and double skin façade in terms of daylighting is minimal as far as a glass of certain specifications is been used. Too much daylight let into the building can cause glare, hence it is preferred to choose glass to admit optimum light with proper specifications be it in terms of VLT, tints, or even thickness.

9.3.C) SOUND CONTROL: Studies prove that double-skin facades have a far better acoustical insulation (up to 10dB) as compared to single skin facades. The ventilation system for the cavity is important in terms of sound transmission. The degree of sound level in a double skin façade would mainly depend on the size and position of the opening in the exterior layer. Studies also prove that the sound insulation depends on the absorbent surfaces within the cavity.

9.3.D) COOLING LOAD REDUCTION: A well-designed double-skin façade will have better solar protection thereby reducing the effect of external factors and cooling load. It is estimated that the additional layer of glazing with a cavity would reduce the insulation by nearly 10%. The reduction, can even, more be enhanced by providing apt shading devices within the cavity space. In-short, the cooling load can be reduced by using a solar control coating, reflective glazing, shading device, and ventilated cavity space.

9.4. ADVANTAGES & DISADVANTAGES OF DOUBLE SKIN FAÇADE (3)

9.4.A. ADVANTAGES:

- Acoustic Insulation
- Thermal Insulation
- Energy savings and reduced environmental impact
- Thermal comfort, the temperature of the internal wall
- Low U value

9.4.B. DISADVANTAGES:

- Higher construction cost
- Reduction of usable office space
- Additional maintenance and operational cost
- Increased Construction weight

10. SIMULATION BETWEEN SINGLE SKIN DOUBLE GLAZED FAÇADE AND DOUBLE SKIN HEAT ABSORBING FAÇADE:

10.1 ASSUMPTIONS: An average constant temperature is assumed for the cavity to calculate the annual cooling loads. The cavity depth used for simulation is nearly 1000mm. with an inlet and outlet of nearly 0.3m wide for all orientations. Since it is a hypothetical situation no buildings are considered nearby which would cast a show on the glass building. Double skin façade has an opaque inner screen of ACC block and outer glazed skin of heat-absorbing glass making It a total U value of 0.9 W/m^2 and a single skin façade using double glazing glass with a total U value of 2.1 W/m^2.The weather file of Jaipur is considered for energy modelling and it is done in two software which are IES and Equest.

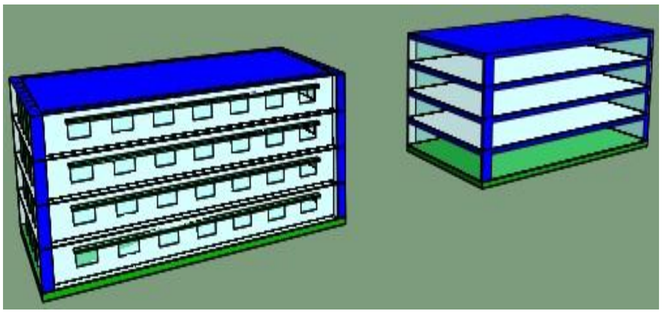

Fig 18: Energy Model of Double skin façade and single skin facade

10.2 COMPARISON OF ENERGY CONSUMPTIONS: For comparison purposes, three cases are compared on the same ground which is the baseline study, double skin façade with an opaque inner wall and outer high-performance glass, and a single skin façade with double glazing. The baseline study is the least and is always compared to the other two cases to find which parameter would be financially stable for the client in a hot and dry climate.

Energy Consumption (Kwh)	**Baseline (ASHRAE 90.1)**	**Double Skin Façade with single glazing**	**Single skin façade with double glazing**
Space Cooling	1,59,308	1,73,904	2,06,915
Heat Reject.	-	-	-
Refrigeration	-	-	-
Space Heat	2	-	-
HP Supp.	-	-	-
Hot Water	-	-	-
Vent Fans	1,25,055	1,25,055	1,25,055
Pumps & Aux.	111	111	111
Ext. Usage	-	-	-
Misc. Equip.	3,04,533	3,04,533	3,04,533
Task Light	-	-	-
Area Lights	2,85,842	2,85,842	2,85,842
Total kWh	8,74,851	8,89,445	9,22,456
Percentage wrt ASHRAE		**-1.67%**	**-5.44%**
Increase in Energy Consumption wrt ASHRAE		**-14,593**	**-47,605**
Increase in Energy Cost in Rs		**-1,60,528**	**-5,23,680**

Table 3: Comparison of Energy Consumption from simulation

Electric Demand (Kw)	**Baseline (ASHRAE 90.1)**	**Double Skin Façade with single glazing**	**Single skin façade with double glazing**
Space Cooling	919	966	1,099
Heat Reject.	-	-	-
Refrigeration	-	-	-
Space Heat	-	-	-
HP Supp.	-	-	-
Hot Water	-	-	-
Vent Fans	476	476	476
Pumps & Aux.	-	-	-
Ext. Usage	-	-	-
Misc. Equip.	1,012	1,012	1,012
Task Light	-	-	-
Area Lights	1,123	1,123	1,123
Total kW	**3,530**	**3,577**	**3,710**

Table 4: Comparison of Electric Demand from simulation

10.3. INFERENCES/CONCLUSION

10.3.A. BASELINE SCENARIO: The total energy consumption is 8, 74,851 kWh with an energy demand of 3,530 kW which is modelled as per appendix G.

10.3.B. DOUBLE SKIN FAÇADE WITH SINGLE GLAZING: In this scenario with double skin facade the total energy consumption is 8,89,445 kWh with an energy demand of 3,577 kW. The increase in the consumption of energy wrt to ASHRAE is 14,593 kWh i.e. increase in the cost of energy by 1.67% which accounts for nearly Rs 1, 60,528. Considering Rs 11 for each unit

10.3.C. SINGLE SKIN FAÇADE WITH DOUBLE GLAZING: In this scenario with double glazing the total energy consumption is 9,22,456 kWh with an energy demand of 3,710 kW. The increase in the consumption of energy wrt to ASHRAE is 47,605 kWh i.e. increase in the cost of energy by 5.44% which accounts for nearly Rs 5, 23,680. Considering Rs 11 for each unit

With the current set of modeling parameters, the project would be able to achieve the lowest energy consumption by using double-skin façade with high-performance glasses. It is in this scenario that the increase in energy cost in the least as compared to the baseline.

11. DESIGN GUIDELINES FOR GLASS BUILDINGS IN HOT AND DRY CLIMATE:

- Orient the buildings with the longer axis along the east-west direction and width along the north-south direction.
- Promote passive cooling techniques in the building to reduce the HVAC load.
- Block the direct sun radiation by various shading means.
- Larger windows are placed on the northern façade as direct solar radiation is the least on this façade.
- Windows must be small on the east and west sides and must be adequately shaded
- On the east and west opening design closely spaced vertical shades to cut of the low morning and evening sun.

- Intelligent facades can be proposed for east and west facades so that views from the windows can be preserved.
- Larger windows can be placed on the southern façade as it is relatively easier to shade it from the high summer sun with a horizontal sunshade. This can also allow the desirable winter sun.
- Higher reflectance of internal surfaces should be higher for better distribution of daylight (E.g. Whitewash- 0.7-0.8)
- A high thermal mass will retard heat transfer from the interior to the exterior during daytime and when the temperature falls at night, the walls will re-radiate the thermal energy keeping the inner spaces warm.
- Avoid glass below sill level as it is not of much help and would help to comply with the ASHRAE standards of WWR as 40 to some extent
- Glasses below the U value of 1.9 W/m^2K proves to be of great help in reducing the solar gain
- Open Plan offices have a lot of flexibility and each desk uses natural ventilation and daylight to the maximum.
- Have the workspaces perpendicular to the envelope to avoid glare.

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