Assessment of Fenestration Design Towards Energy Conservation for an Office Building

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Abstract: The aim of this paper is to investigate the influence of fenestration design towards achievability of energy conservation and optimum daylighting in office buildings. Energy and daylighting simulation will be carried out by using climate data. Data regarding several parameters of building envelope (wall, roof, window, shading etc.) will be required to carry out the simulations. ECBC recommended values will be used to check the achievability of desired results in warm and humid climate. Analytical tools to be used to process the data are eQUEST (DOE-2.2), Microsoft Excel and Sefaira. The key results of the study focus upon the indices and values of windows and shading devices, that helps in achieving the optimum balance between daylighting and energy consumption in an office building in warm and humid climate. This study will determine the most favorable combination of window and other associated factors towards optimum balance between daylighting and energy efficiency. The future studies can be based on dynamic fenestration system design to improve the energy efficiency while allowing daylighting.

Index Terms **- Fenestration, Glazing, Shading Devices, Daylighting, Energy Efficiency**

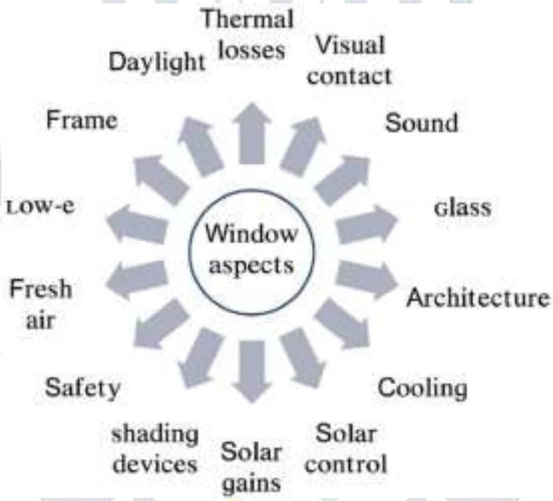


Figure 1. Graphical Abstract

I. INTRODUCTION

Fenestration is an architectural term that refers to the arrangement, proportion, and design of window, skylight, and door systems in a building. Fenestration can serve as a physical and/or visual connection to the outdoors, as well as a means to admit solar radiation for natural lighting (daylighting), and for heat gain to a space. Fenestration can be fixed or operable, and operable units can allow natural ventilation to aspace and egress in low-rise buildings. Fenestration affects building energy use through four basic mechanisms: thermal heat transfer, solar heat gain, air leakage, and daylighting. The energy effects of fenestration can be minimized by (1) using daylight to offset lighting requirements, (2) using glazing's and shading strategies to control solar heat gain to supplement heating through passive solar gain and minimize cooling requirements, (3) using glazing to minimize conductive heat loss, (4) specifying low-air-leakage fenestration products, and (5) integrating fenestration into natural ventilation strategies that can reduce energy use for cooling and fresh air requirements.

II. LITERATURE REVIEW

2.1. Fenestration Components

Fenestration components include glazing material, either glass or plastic; framing, mullions, muntin bars, dividers, and opaque door slabs; and shading devices such as louvered blinds, drapes, roller shades, and awnings.

2.1.1. Glazing units

A glazing unit may consist of a single glazing or multiple glazing. Units with multiple glazing layers, sometimes called insulating glazing units (IGUs), are hermetically sealed, multiple-pane assemblies consisting of two or more glazing layers held and bonded at their perimeter by a spacer bar typically containing a desiccant material. The desiccated spacer is surrounded on at least two sides by a sealant that adheres the glass to the spacer. Figure 2 shows the construction of a typical double-glazing unit.

2.1.2. Glazing

The most common glazing material is glass, although plastic is also used. Both may be clear, tinted, coated, laminated, patterned, or obscured. Clear glass transmits more than 75% of the incident solar radiation and more than 85% of the visible light. Tinted glass is available in many colors, all of which differ in the amount of solar radiation and visible light they transmit and absorb. Coatings on glass affect the transmission of solar radiation, and visible light may affect the absorptance of room-temperature.

2.1.3. Spacer

The spacer separates the panes of glass and provides the surface for primary and secondary sealant adhesion. Several types of spacers are used today. Each type provides different heat transfer properties, depending on spacer material and geometry.

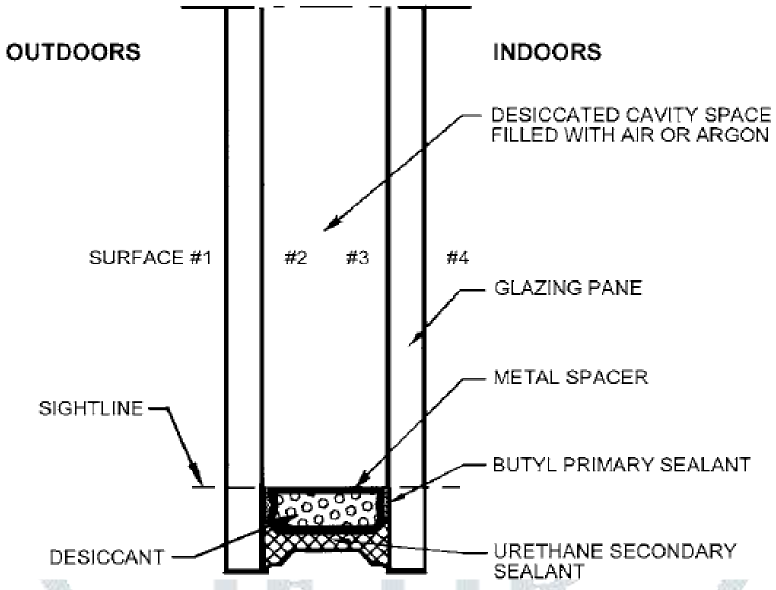


Figure 2: Double-Glazing Unit Construction Detail, (Source: ASHRAE, 2009)

2.1.4. Sealant(s)

Several different sealant configurations are used successfully in modern glazing unit construction. In all sealant configurations, the primary seal minimizes moisture and hydrocarbon transmission. In dual-seal construction, the secondary seal provides structural integrity between the glazing units. A secondary seal ensures long-term adhesion and greater resistance to solvents, oils, and short-term water immersion. In typical dual-seal construction, the primary seal is made of compressed polyisobutylene (PIB), and the secondary seal is made of silicone, polysulfide, or polyurethane.

2.1.5. Desiccants

Typical desiccants include molecular sieve, silica gel, or a matrix of both materials. Desiccants are used to absorb moisture initially trapped in the glazing unit during assembly or that gradually diffused through the seals after construction.

2.1.6. Gas Fill

The hermetically sealed space between glass panes is most often filled with air. In some cases, argon and krypton gas are used instead, to further reduce energy transfer.

2.1.7. Framing

The three main categories of window framing materials are wood, metal, and polymers. Wood has good structural integrity and insulating value but low resistance to weather, moisture and organic degradation (from mold and insects). Metal is durable and has excellent structural characteristics, but it has very poor thermal performance. The metal of choice in windows is almost exclusively aluminum, because of its ease of manufacture, low cost, and low mass, but aluminum has a thermal conductivity roughly 1000 times that of wood or polymers.

2.1.8. Shading

Shading can be located either outdoors or indoors, and in some cases, internal to the glazing system (between the glasses). Materials used include metal, wood, plastic, and fabric. Shading devices are available in a wide range of products that differ greatly in their appearance and energy performance. They include indoor and outdoor blinds, integral blinds, indoor and outdoor screens, shutters, draperies, and roller shades. Shading devices on the outdoor side of the glazing reduce solar heat gain more effectively than indoor devices.

2.2. Fenestration Heat Transfer

Heat flows through a fenestration assembly in three ways: conduction, convection, and radiation. Conduction is heat traveling through a solid, liquid or gas. Convection is the transfer of heat by the movement of gases or liquids, like warm air rising from a candle flame. Radiation is the movement of energy through space without relying on conduction through the air or by movement of the air, the way you feel the heat of a fire. There are two distinct types of radiation or radiation heat transfer:

- Long-wave radiation heat transfer refers to radiant heat transfer between objects at room or outdoor environmental temperatures. These temperatures emit radiation in the range of 3–50 microns.

- Short-wave radiation heat transfer refers to radiation from the sun (which is at a temperature of 6000K) and occurs in the 0.3–2.5 micron range. This range includes the ultraviolet, visible, and solar-infrared radiation.

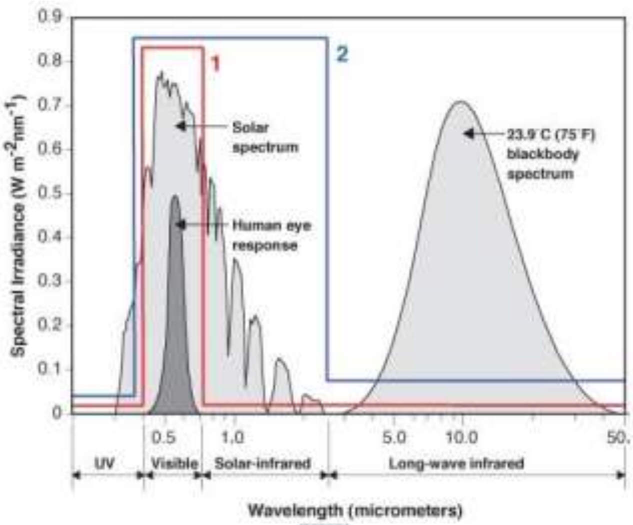


Figure 3: Ideal spectral transmittance for glazing's in different climates, (Source: McCluney, 1998)

1. Idealized transmittance of a glazing with a low-E coating designed for low solar heat gain. Visible light is transmitted and solar-infrared radiation is reflected. Long-wave infrared radiation is reflected back in to the interior. This approach is to reduce solar heat gain and is suitable in almost all climates.

2. Idealized transmittance of a glazing with a low-E coating designed for high solar heat gain. Visible light and solar-infrared radiation are transmitted. Long- wave infrared radiation is reflected back in the interior. This approach is more commonly used in cold climates where solar gain is wanted.

2.3. Characteristics of Glazing

2.3.1. Characteristics of glazing that affect radiant energy transfer

2.3.1.1. Transmittance

Transmittance refers to the percentage of radiation that can pass through glazing. Transmittance can be defined for different types of light or energy, e.g., visible transmittance, UV transmittance, or total solar energy transmittance. Transmission of visible light determines the effectiveness of a type of glass in providing daylight and a clear view through the window.

2.3.1.2. Reflectance

It is the ratio of the flux reflected by a surface to the incident flux. The quantity reported may be total reflectance, specular (regular) reflectance, diffuse reflectance or spectra1 reflectance depending on the component measured (BIS, 1987). The natural reflectivity of glass is dependent on the type of glazing material, the quality of the glass surface, the presence of coatings, and the angle of incidence of the light.

2.3.1.3. Absorptance

Energy that is not transmitted through the glass or reflected off its surfaces is absorbed. Once glass has absorbed any radiant energy, the energy is transformed into heat, raising the glass temperature. Absorptance is the ratio of the flux absorbed by the medium to the incident flux. The sum of the total reflectance, total transmittance and the absorptance is one (BIS, 1987).

2.3.1.4. Emittance

When solar energy is absorbed by glass, it is either convected away by moving air or reradiated by the glass surface. This ability of a material to radiate energy is called its emissivity. Window glasses, along with all other objects, typically emit, or radiate, heat in the form of long-wave far-infrared energy. The wavelength of the long-wave far-infrared energy varies with the temperature of the surface. This emission of radiant heat is one of the important heat transfer pathways for a window. Thus, reducing the window's emission of heat can greatly improve its insulating properties.

2.4. Characteristics of glazing that are the basis for quantifying energy performance

2.4.1. U-factor

When there is a temperature difference between inside and outside, heat is lost or gained through the window frame and glazing by the combined effects of conduction, convection, and long-wave radiation. The U-factor of a window assembly represents its overall heat transfer rate or insulating value. For windows, it expresses the total heat transfer coefficient of the system (in Btu/hr-sf-°F), and includes conductive, convective, and radiative heat transfer. It represents the heat flow per hour (in Btus per hour or watts) through each square foot of window for a 1 degree Fahrenheit temperature difference between the indoor and outdoor air temperature.

2.4.2. Solar Heat Gain Coefficient

Regardless of outside temperature, heat can be gained through windows by direct or indirect solar radiation. The ability to control this heat gain through windows is characterized in terms of the solar heat gain coefficient (SHGC) or shading coefficient (SC) of the window. Solar Heat Gain Coefficient (SHGC) is defined as the ratio of solar heat gain through a window to the solar radiation striking the outer surface, for a given incidence angle (Wilson, 2004). The SHGC is also affected by shading from the frame as well as the ratio of glazing and frame.

2.4.3. Visible Transmittance

Visible transmittance (VT) also referred to as visible light transmittance (VLT), is an optical property that indicates the amount of visible light transmitted through the glass. It affects energy by providing daylight that creates the opportunity to reduce electric lighting and its associated cooling loads. Generally a higher value of τ_v is desirable, leading to more daylight indoors and associated psychological benefits, although in specific cases a low value may need to be chosen, e.g. if the contrast becomes too great for work with computer monitors.

2.4.4. Air Leakage

Heat loss and gain also occur by air leakage through cracks around sashes and frames of the window assembly. This effect is often quantified in terms of the amount of air (cubic feet or cubic meters per minute) passing through a unit area of window (square foot or square meter) under given pressure conditions.

2.5. Daylighting

Daylighting is the illumination of building interiors with sunlight and sky light and is known to affect visual performance, lighting quality, health, human performance, and energy efficiency. Daylighting in office buildings, widely recognized as an important energy-conservation design strategy, requires careful architectural design in order for maximum benefits to be realized (Russell Johnson, 1985). Daylight admission can displace the need for electric lighting at the perimeter zone with vertical windows (side lighting) and at the core zone with skylights (top lighting). Lighting and its associated cooling energy use constitute 30 to 40% of a non-residential building's energy use. Energy use reductions can be achieved, perhaps less reliably, in residential buildings with manual or automated switching of electric lights on and off to match space occupancy. For internal-load-dominated buildings, daylight admission must be balanced against solar heat admission to achieve optimum energy efficiency.

2.6. Fenestration and Annual Energy Performance

Instantaneous energy performance indices (U-factor, solar heat gain coefficient, air leakage, etc.) are typically used to compare fenestration systems under a fixed set of conditions. However, the absolute and relative effect of these indices on a building's heating and cooling load can fluctuate as environmental conditions change. The four basic mechanisms of fenestration energy performance (thermal transfer, solar heat gains, air leakage, and daylighting) should all be taken into account but are not independent of many other parameters that influence performance. As a result, the annual energy performance of fenestration systems can be accurately determined only when many variables are considered. Building type and orientation, climate, microclimate (shading from adjacent buildings, trees, and terrain), occupant usage patterns, and certain HVAC parameters can significantly affect the annual energy effects of fenestration systems.

2.7. Fenestration and Building Geometry Factors

To design efficient fenestration, one must account for the climate, building type, and the physical properties of glazing and framing materials, such as visual transmittance, solar heat gain coefficient, and thermal conductance. Much less considered but no less important, are building geometry factors, such as building aspect ratio, lease span, window orientation, window area, size and position of shading. Geometry factors are defined by a building form, type, structural and HVAC systems used in common architectural practices. Building and fenestration geometry alone can affect energy consumption and therefore it is important to make objective energy conserving and daylighting decisions when defining a building's form, orientation, and enclosure type at the early stages of the building design process.

2.7.1. Building form

Building form should be thermally optimized to allow the lowest heat losses in winter while allowing minimum summer heat gains. Square shaped buildings have the least outside surface- to-volume ratio. This shape might be the optimum for buildings with negligible radiation effects. However, when considering radiation effects in contemporary buildings with large window areas, orientation with the E-W as major axis is the optimization trend, with different magnitudes depending on building type and location (Al-Homoud, 1997). (Elisabeth Gratia, 2003) have defined the volume to surface area ratio (V/S) as "compactness" (C) of a form. Here the surface area of a building includes wall surfaces, roof surface, and ground surface. The building with a V/S of 1.24 (highly compact) requires 20.73% less space heating energy while compared to a building with a V/S of 0.84 (the least compact form studied).

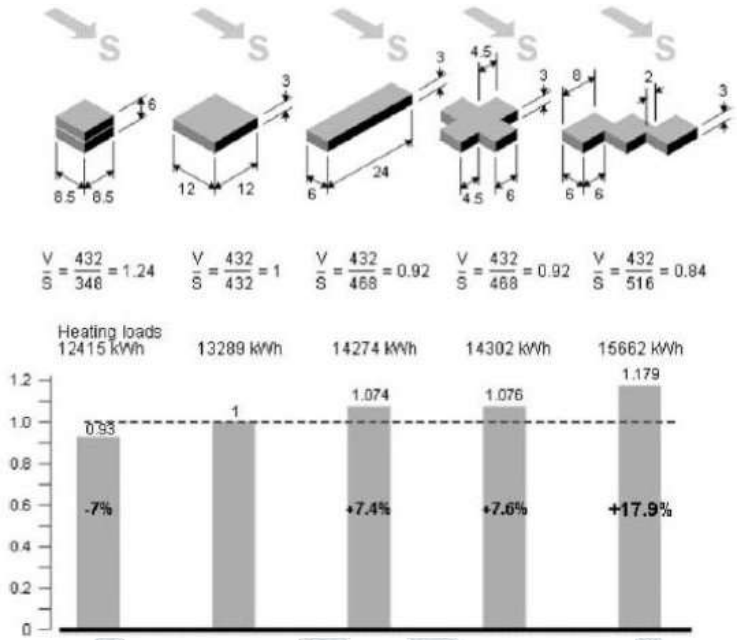


Figure 4: Impact of the building shape on heating loads, (Source: Elisabeth Gratia, 2003)

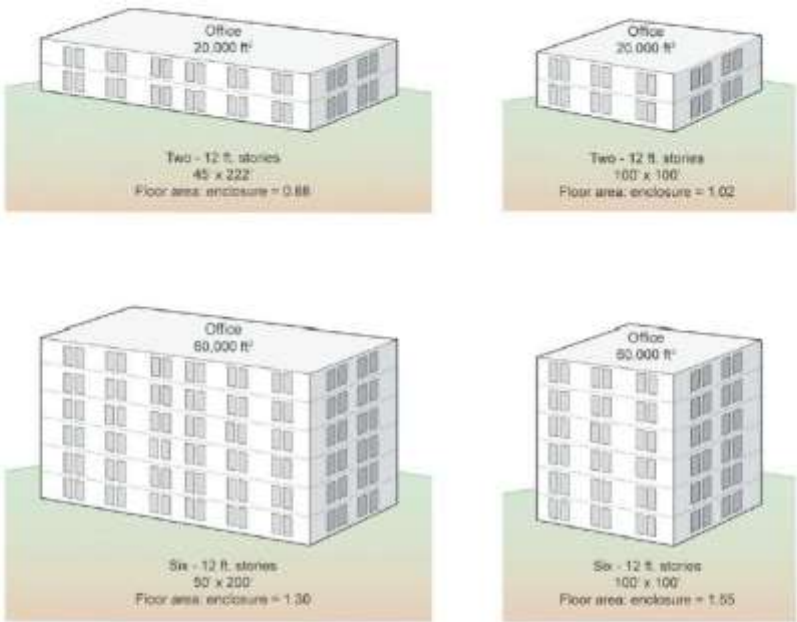


Figure 5: Floor area-to-enclosure area ratios for different building forms, each with 10,000 ft2 (930 m2) floor plate, (Source: Straube, 2012)

2.7.2. Window to Wall Ratio and Orientation

The window to wall ratio (WWR) corresponds to: WWR = Area of Exterior Openings (excluding mullions and window frames) / Total Wall Area of Exterior Façade (width × floor to ceiling height). (Elisabeth Gratia, 2003) has experimented aiming to determine which orientation is most preferable for glazing to be positioned in conjunction with external shading devices. According to their study, large glazing areas with sun control facing south are preferable compared to north oriented glazing without solar protection. The referenced work provides useful findings on impact building orientation over heating and cooling demands; however it does not account for fenestrations on all four elevations (i.e., only north and south glazing are simulated separately for some cases and only east- west windows are simulated separately in other cases).

2.7.3. Shading

The effect of shading on visual and thermal comfort and energy performance is determined by three main parameters: (i) the type of shading device (ii) the thermal and optical properties of the shading device and (iii) the considered control of the shading device (if any) (Athienitis A. T., 2005). To determine the shading efficiency regarding minimizing the incident solar radiation on any surface, the variation in solar radiation intensity and the position of sun over a period of time must be considered. Climatic conditions and daylight availability play a major role in the design and control of a shading system (Athienitis A. T., 2005).

III. SITE ANALYSIS

3.1. Location

The site is located in the campus of Medha IT Park, Gannavaram. Gannavaram is a neighborhood of the city of Vijayawada, located in Krishna district of the Indian state Andhra Pradesh. The area of the site is 1.38 acres and faces towards south-east.

3.2. Climate
Warm and Humid climate zone

3.3. Site details
Site area - 1.38 acres. Site condition - site is a vacant land with no previous developments. The site is located in a proposed it park campus in Gannavaram.

3.4. Bye law restrictions
Road width = 12m, Setback front = 3 m, Rear and sides = 6 m, Maximum height = 15 m.

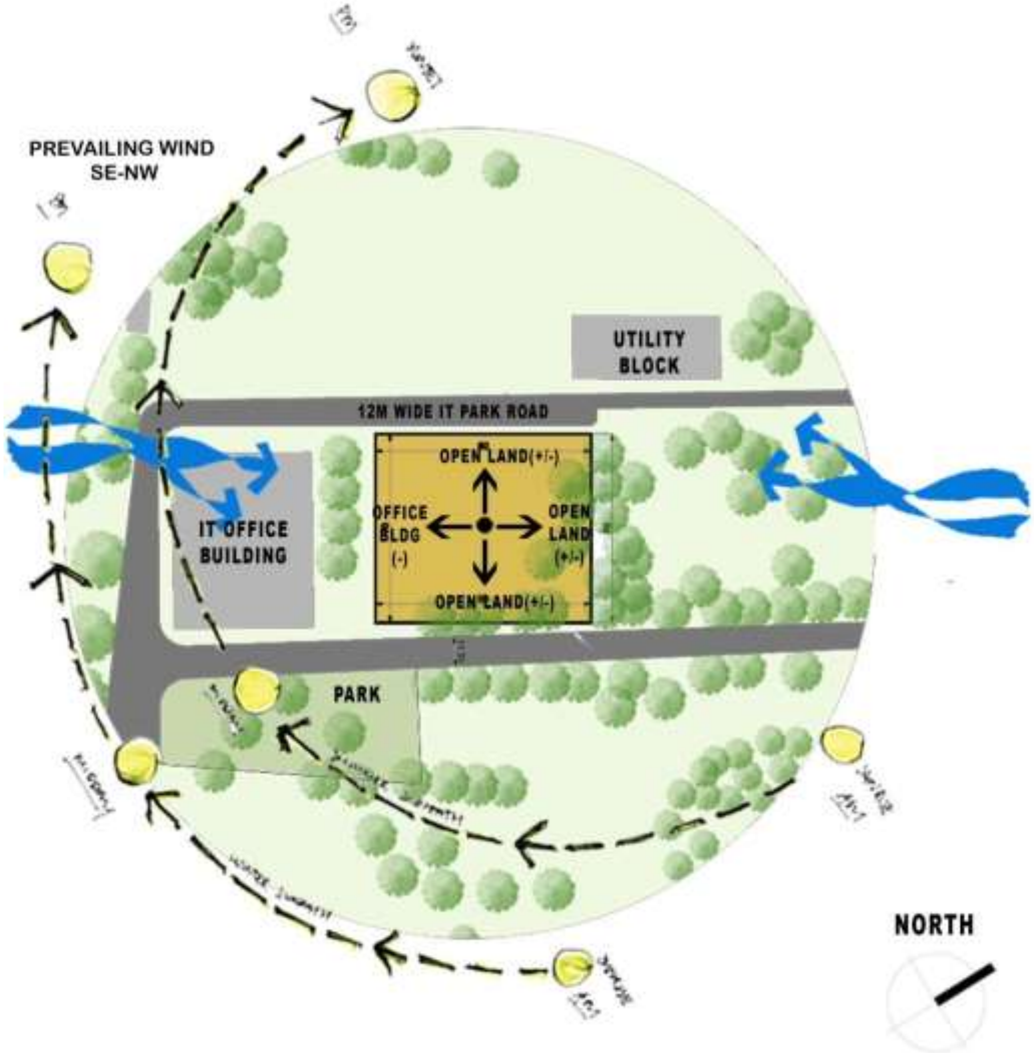


Figure 6: Proposed Site

IV. METHODOLOGY

In order to conduct the research the study is divided into three parts:

A. **Preliminary Simulation Analysis**
This stage involves the analysis of different glazing types on a single prototypical model using the software COMFEN. The glazing types are divided based on number of panes and glass properties. This stage further investigates the effect of light shelf and shading device on a single prototypical model.

B. Parametric Analysis
To perform the analysis five prototypical forms has been selected based on their different aspect ratios, compactness ratios and lease span. These prototypes are then simulated using the software eQUEST by varying their WWR, orientation, glazing types, window configuration on different facades, window position and adding a standard shading strategy. Further the daylight analysis of all the prototypes has been carried out by using the plugin Sefaira in SketchUP. The models are simulated by varying their window to wall ratio.

V. ANALYSIS AND RESULTS

5.1. Preliminary simulation analysis

5.1.1. Simulation Model Setup

A study model of 6m x 6m room with height 3m was modelled in COMFEN software (Figure 7, 8 & 9). The room has a single window of 3m width and 1.2m height with 0.9 m sill height without shading devices and facing south side. The climate is warm and humid. Lighting load is 10.8 w/m^2 (ECBC recommended) and equipment load is 8w/m^2. The room has 1 person inside. The simulation has been carried out by considering automatic lighting control. The software COMFEN uses Energy Plus as its engine to calculate energy consumption.

Figure 7: Plan and section of the model for simulation

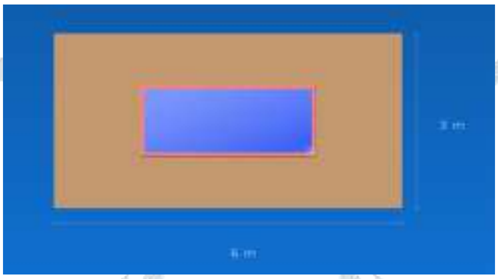


Figure 8: Elevation of the model

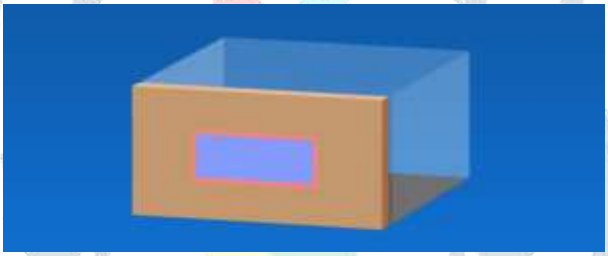


Figure 9: Perspective View of the model

In this study 14 different types glazing were analyzed for their performance of energy efficiency and daylighting (Table 1). The glazing was broadly divided into four categories namely Clear, Tinted, Reflective and Low-e these can be further subdivided into single, double and triple pane glazing.

Table 1: List of glazing types and their properties

S.No.	Glazing Types	SHGC	VLT	U-Value (W/m2-K)
1	Single Clear 6 mm	0.82	0.88	5.82
2	Double Clear (Air)	0.70	0.79	2.69
3	Double Clear (Argon)	0.38	0.70	1.39
4	Triple Clear (Air)	0.33	0.58	1.22
5	Triple Clear (Argon)	0.48	0.66	1.08
6	Single gray 6mm	0.60	0.45	5.82
7	Double Gray (Air)	0.47	0.40	2.69
8	Triple tinted - gray/clear/clear (air)	0.41	0.36	1.74
9	Single reflective glass 6mm	0.52	0.41	5.37
10	Double reflective glass 6mm	0.41	0.36	2.56
11	Triple reflective glass - reflective/clear/clear (air) -- triple	0.36	0.33	1.69
12	Single Low-e 6 mm	0.50	0.74	5.68
13	Double Low Solar Low-E Clear (Air)	0.38	0.70	1.65
14	clear/clear/clear (argon) -- triple; dual low-e;	0.31	0.54	0.82

5.1.2. Analysis of different glazing types

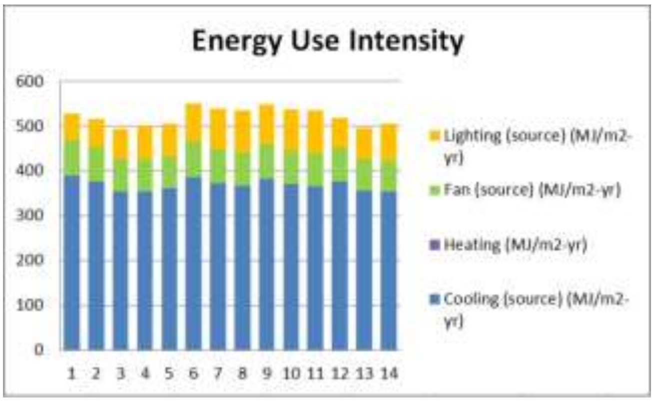


Figure 10: Energy Use Intensity

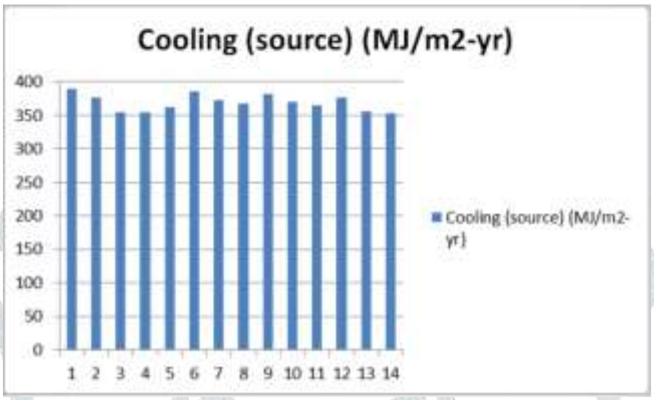


Figure 11: Cooling Load

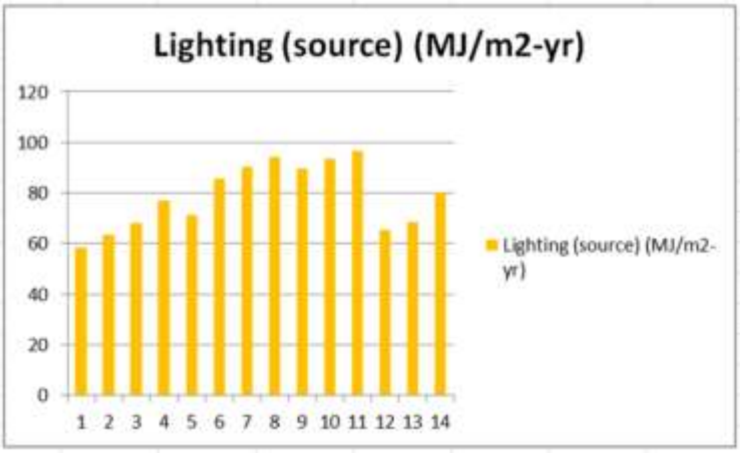


Figure 12: Lighting Load

Energy use intensity decreases with increasing number of panes in case of tinted and reflective glazing. For clear and low-e glazing double panes are the best performers. Single glazing is the worst performer in all cases (Figure 10, 11 & 12).

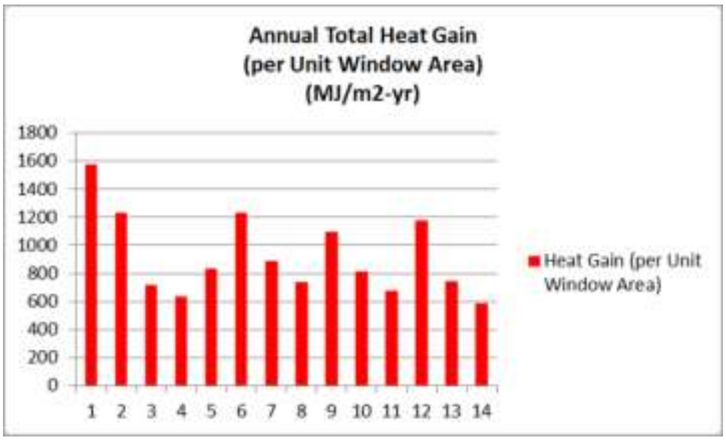


Figure 13: Annual total heat gain

Heat gain decreases with increasing number of panes in case of all but clear glazing. For clear glazing double panes with argon filling are the best performers. Single glazing is the worst performer in all cases.

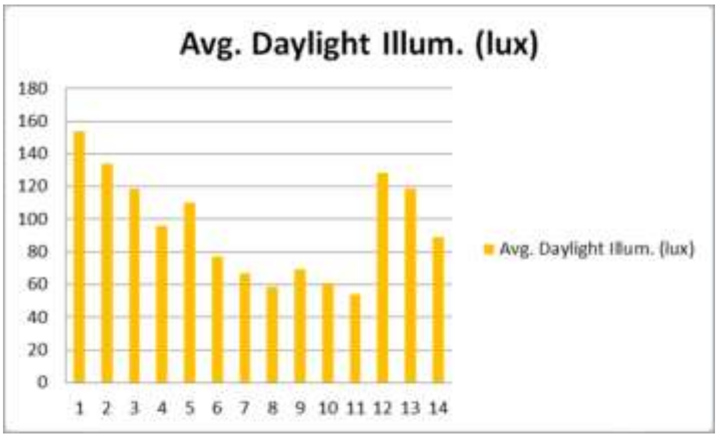


Figure 14: Annual daylight illumination

In all the cases daylighting level decreases with increasing number of glass panes. Clear and low-e glazing is better daylight performers than tinted and reflective glazing. Five glazing types are selected for further study from this simulation study considering single clear glazing as the base case. One glazing is selected from each category for further study. The range of high to Low SHGC and VLT are kept in mind while selecting the glazing types.

5.1.3. Analysis of glazing types with external shading device and light-shelf

An external shading of 500 mm was added to the same model of the glazing typologies.

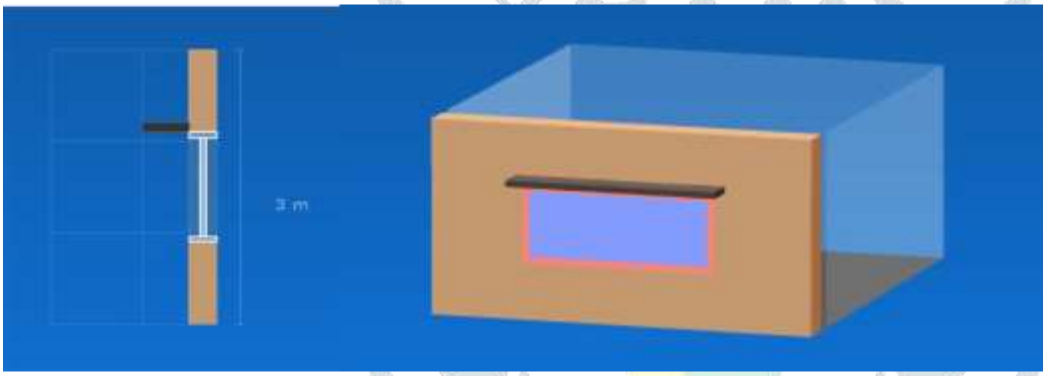
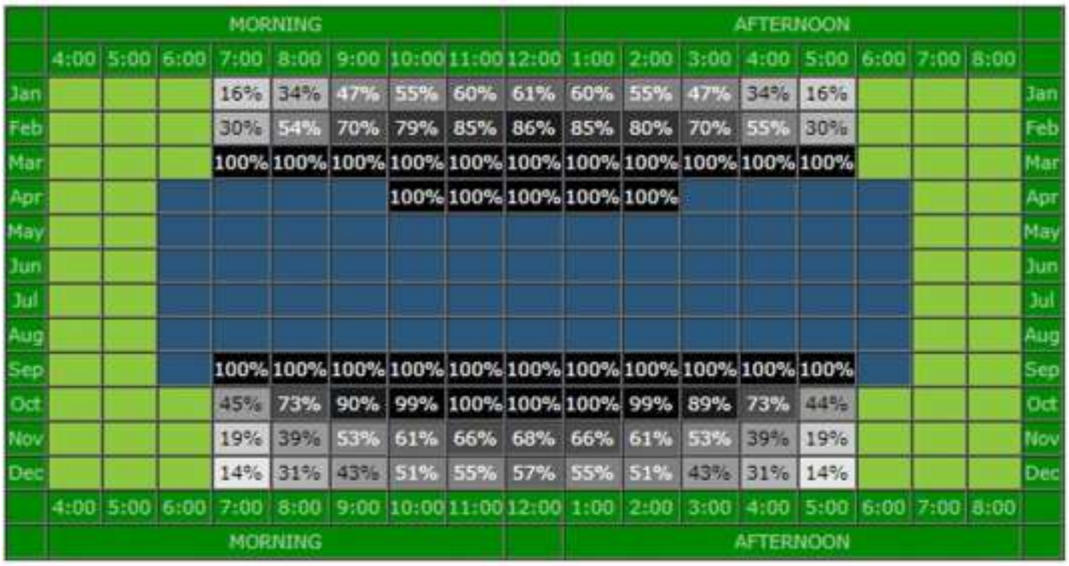


Figure 15: Section and 3d view of shading device on model



	MORNING									AFTERNOON								
	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	
Jan				16%	34%	47%	55%	60%	61%	60%	55%	47%	34%	16%				Jan
Feb				30%	54%	70%	79%	85%	86%	85%	80%	70%	55%	30%				Feb
Mar				100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%				Mar
Apr							100%	100%	100%	100%	100%							Apr
May																		May
Jun																		Jun
Jul																		Jul
Aug																		Aug
Sep				100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%				Sep
Oct				45%	73%	90%	99%	100%	100%	100%	99%	89%	73%	44%				Oct
Nov				19%	39%	53%	61%	66%	68%	66%	61%	53%	39%	19%				Nov
Dec				14%	31%	43%	51%	55%	57%	55%	51%	43%	31%	14%				Dec
	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	
	MORNING									AFTERNOON								

Figure 16: Showing annual shading percentage on the window due the external shading device (Source: Gronbeck, 2009)

The output table (Figure 16) has a row for each month, and a column for each hour. The color of the cell indicates the fraction of the window area that the overhang is shading at that time on the 15th day of that month. A black cell means that the window is totally shaded. A white cell means that the window is entirely unshaded. Grey cells indicate the degree of partial shading. A green cell indicates that the sun is below the horizon. A blue cell indicates that the sun is above the horizon, but not shining on the window.

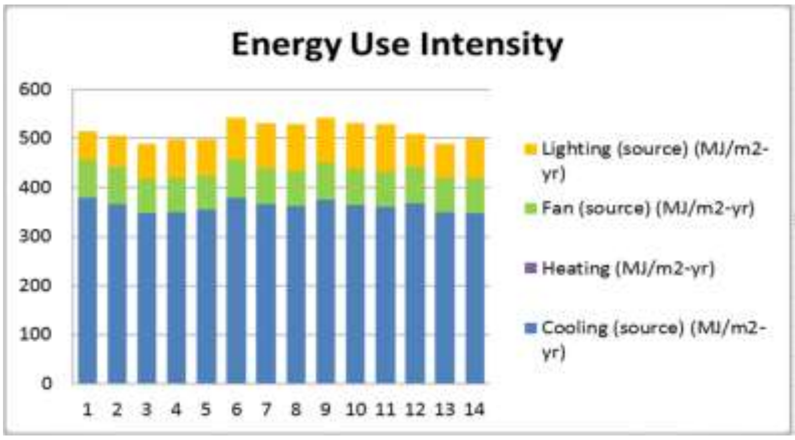


Figure 17: Glazing types with shading device

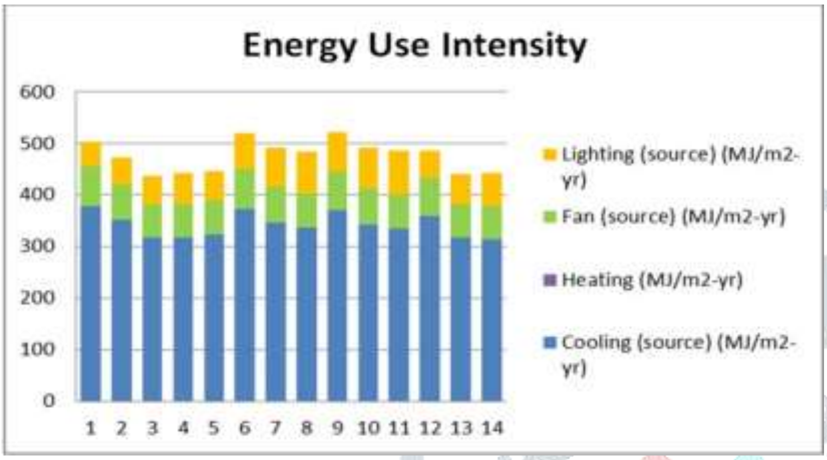


Figure 18: glazing types with shading device and light shelf

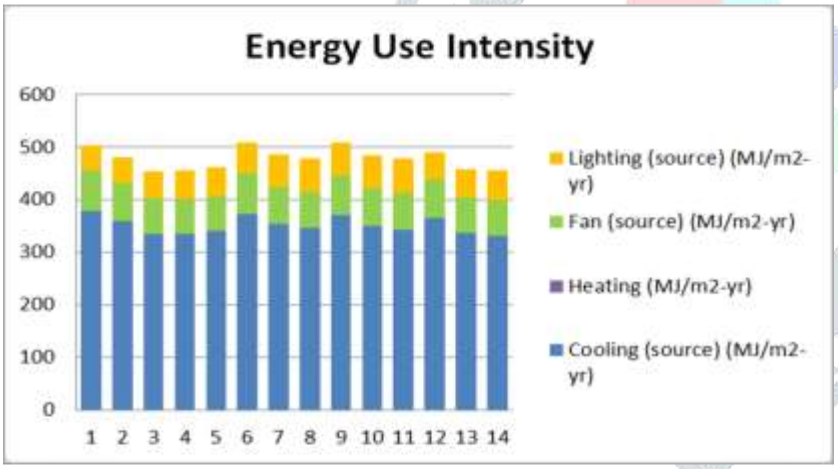


Figure 19: glazing types with shading device and clear glass light shelf

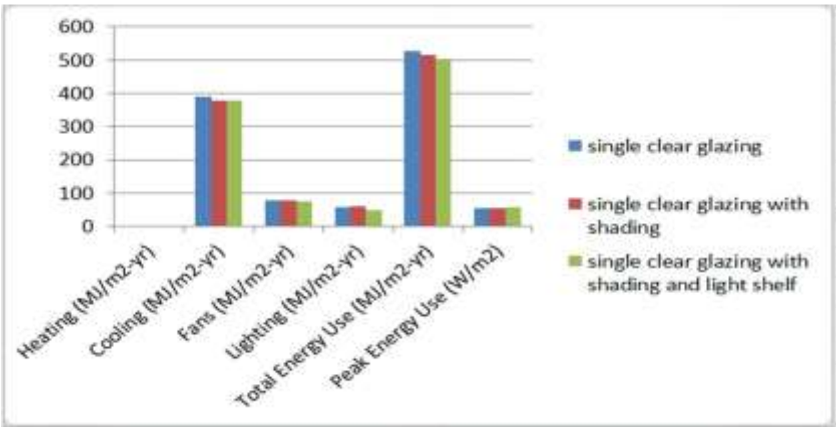


Figure 20: energy use comparison of single clear glazing, single clear glazing with shading device and single clear glazing with both shading and light shelf

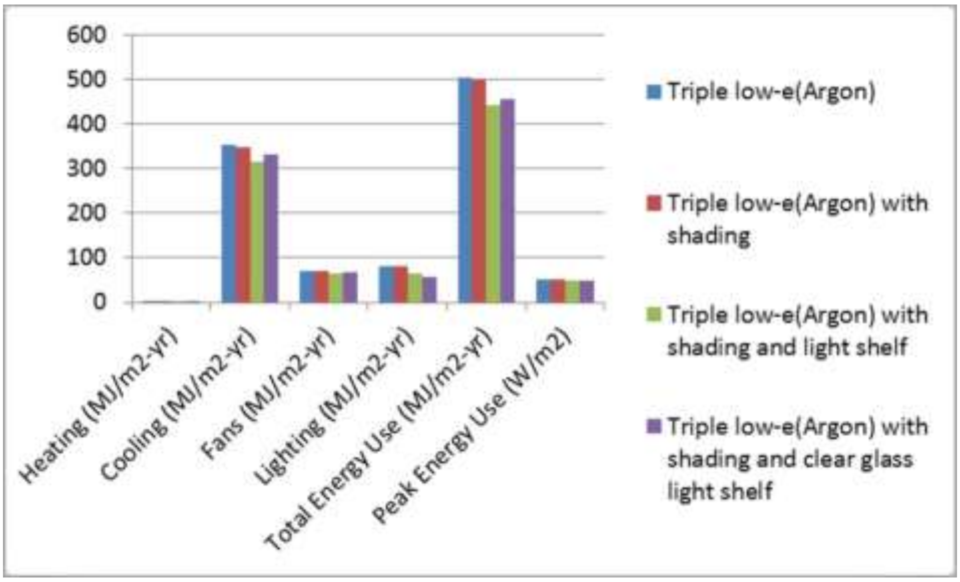


Figure 21: energy use comparison of single grey tinted glazing, single grey tinted glazing with shading device and single grey tinted glazing with both shading and light shelf

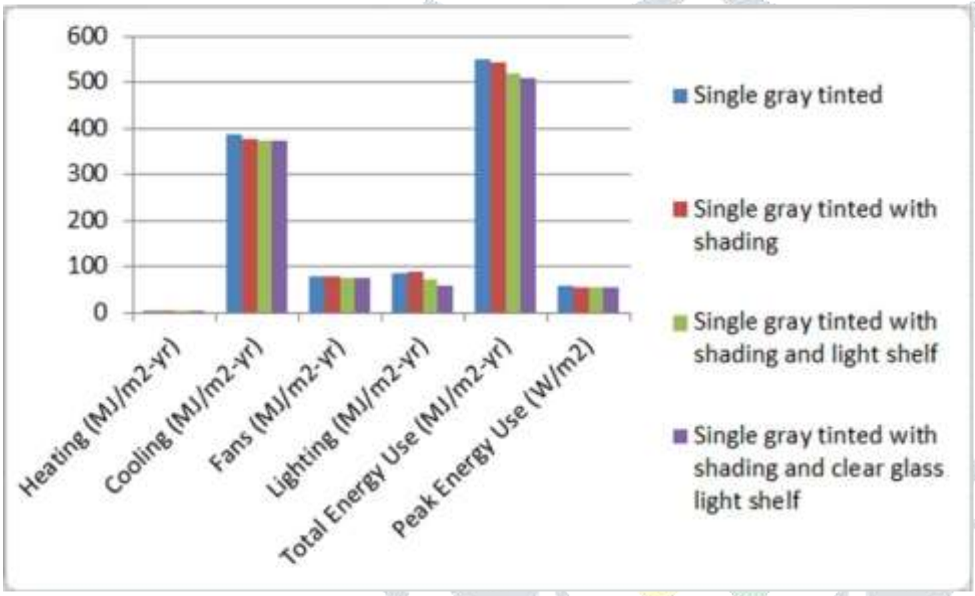


Figure 22: energy use comparison of Triple low–e glazing, Triple low–e glazing with shading device and Triple low–e glazing with both shading and light shelf

As per the graph, for clear glazing and tinted glazing the effect of shading devices and light shelves improve the energy efficiency. While low-e glazing has negligible effect of shading device but light shelves improve the energy efficiency.

5.2. Parametric analysis

5.2.1. Simulation Model Setup

Five different building forms of the same volume and built-up area were selected for the analysis to have the same amount of conditioned space. The details of the model are given in Table 2. The buildings are analyzed on the basis of multiple iterations of window to wall ratio, glazing type, orientation, shading, window size and position.

The prototype models are analyzed with window to wall ratio of 0%, 20%, 30%, 40%, 50%, 60%, 70% and 80% and five different types of glazing given in Table 3.

The location is Vijayawada and the climate is warm and humid. Lighting load is 1.1 (ECBC recommended) w/sft and equipment load is 1.5 w/sft (ECBC recommended). Maximum design occupancy is 100 sf/person (ECBC recommended). Typical office operation hours is 8am to 5pm. The simulations has been performed by allowing automatic daylight control.

The building enclosure such as roof and wall construction has been kept fixed for all the simulations to understand the effect fenestration parameter changes. Details of roof and wall construction are given in Figure 24.

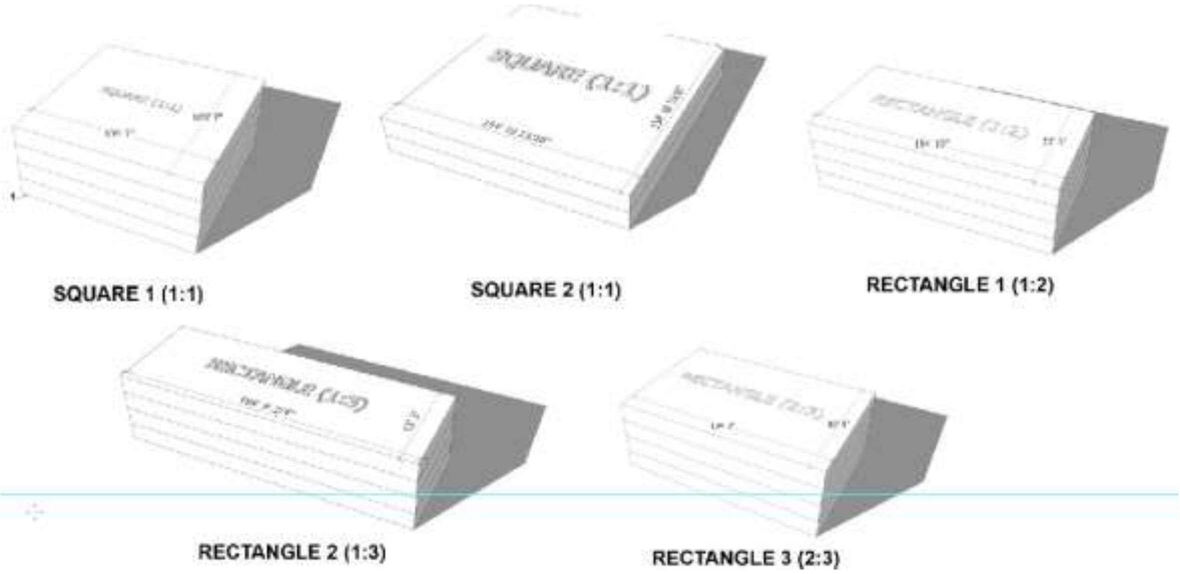


Figure 23: Models for simulation

Table 2: Details of models for simulation

FORM	TOTAL HEIGHT	FLOOR AREA (SQ. FEET)	TOTAL BUILTUP AREA (SQ. FEET)	VOLUME (CUBIC FEET)	DIMENSION	PERIMETER	BUILDING ASPECT RATIO	COMPACTNESS RATIO (V/S)	ENCLOSURE RATIO (F/E)
SQUARE 1	12X4 = 48'	12000	48000	576000	109.55' X 109.55'	438.20'	1:1	12.8	1.45
SQUARE 2	12X2 = 24'	24000	48000	576000	154.90' X 154.90'	619.6'	1:1	9.2	1.23
RECTANGLE 1	12X4 = 48'	12000	48000	576000	154.77' X 77.45'	464.78'	1:2	12.4	1.39
RECTANGLE 2	12X4 = 48'	12000	48000	576000	189.73' X 63.25'	505.96'	1:3	11.9	1.32
RECTANGLE 3	12X4 = 48'	12000	48000	576000	134.17' X 89.44'	447.22'	2:3	12.6	1.43

Table 3: Glazing typologies to be simulated

S.No.	Glazing Types	SHGC	VLT	Centre Glass U-Value (W/m2-K)
1	Single Clear	0.81	0.88	1.09
2	Double Clear	0.76	0.81	1.09
3	Single Tint Grey	0.59	0.43	0.46
4	Double Ref-A Clear-L	0.14	0.07	0.49
5	Double Low-E (e2=.1) Clear	0.56	0.65	0.31

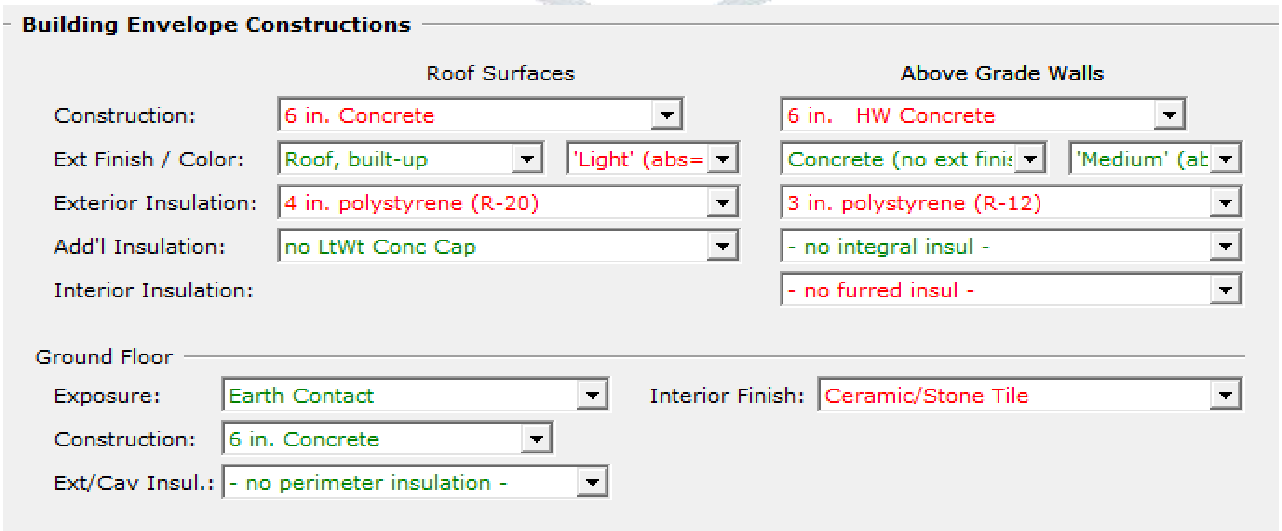


Figure 24: Details of roof and wall constructions, (Source: eQUEST software)

5.2.2. Analysis of WWR vs. Glazing Types

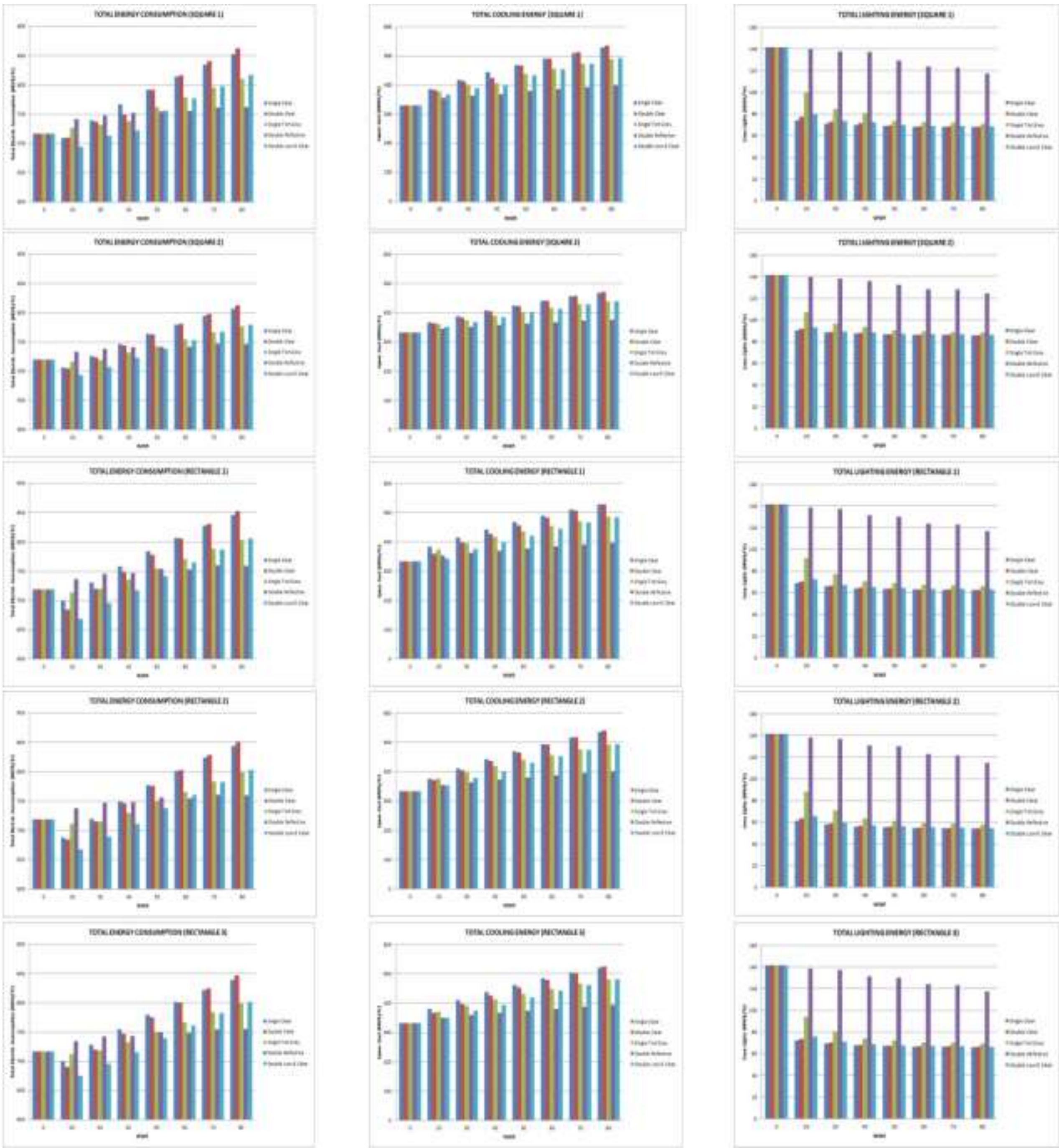


Figure 25: simulation of WWR vs. glazing type based on different forms

Observations:

Total energy consumption:

- Energy consumption decreases at 20% WWR thereafter it rises with rising WWR.
- Energy consumption is minimum for 20% WWR with low-e glazing.
- Upto 40% WWR double low-e glazing is the best performer, beyond that double reflective is the best performer.
- Double reflective glazing is only marginally affected by increasing WWR.

Cooling energy consumption:

- Cooling load increases with rise in WWR.
- Double reflective glazing has almost consistent cooling load with increasing WWR.
- Double reflective glazing is the best performer in terms of cooling energy consumption in almost all cases.
- Single and double clear glass are the worst performers in terms of cooling load.

Lighting energy consumption:

- Lighting load decreases with rise in WWR upto 30%-40% beyond that it becomes constant.
- For single and double clear glazing lighting load is almost consistent.
- For single tint grey lighting load decreases upto 50% WWR and becomes constant beyond that.
- Beyond 50% WWR the lighting load is constant hence; there is no effect of daylighting on energy savings.
- High lighting load for double reflective glazing means daylighting does not have much of a contribution in energy conservation.

5.2.3. Analysis of WWR vs. Building Orientation

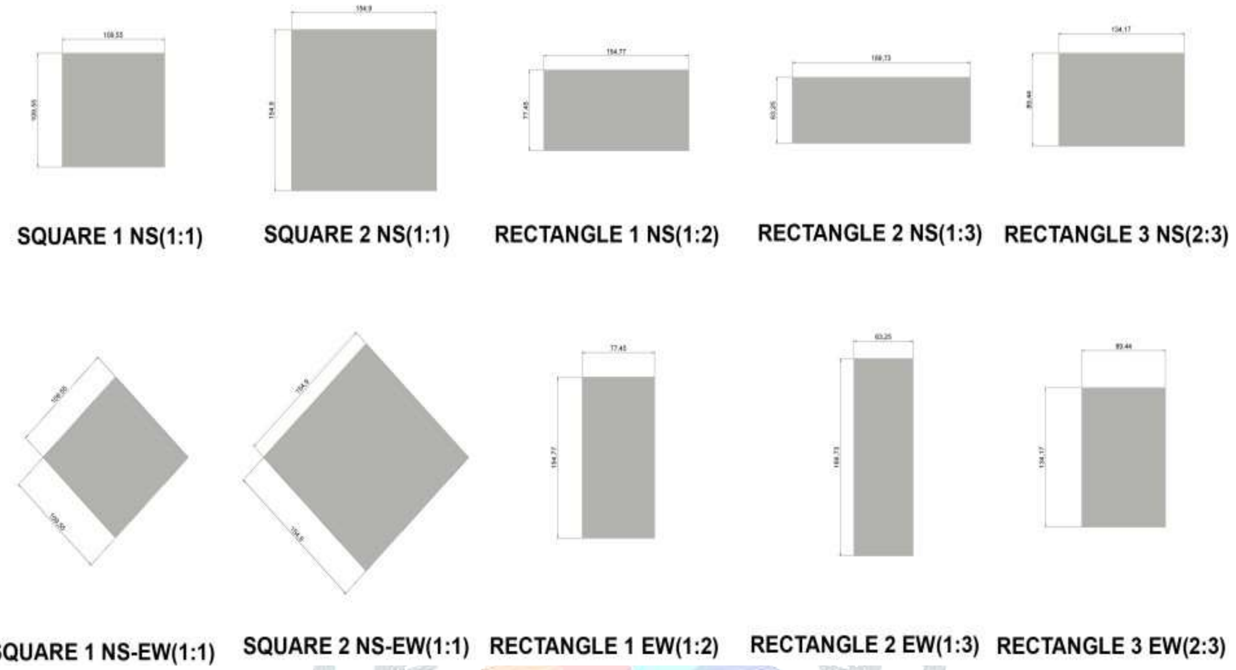


Figure 26: Building forms oriented in NS and EW directions

Five different buildings forms are oriented on north-south and east-west directions as shown in Figure 26 above to analyses the energy consumption.

Observations:
Total energy consumption:

-For square form orientation has little effect on energy consumption.
-Effect of orientation on energy consumption in rectangle 2 is more than rectangle 1&3.
-More slender the floor plate more it is effected by orientation.
-For double reflective glazing the effect of orientation and form is constant with rising WWR.
-For WWR upto 40% rectangle 2 is the best option while for WWR beyond 40% square 2 is the best option.

Cooling energy consumption:

-Orientation has negligible impact on cooling energy consumption of square form.
-East-West facing rectangle consumes more cooling energy than north-south facing rectangular form.
-Effect of orientation is more in more slender rectangle.
-Square 2 is the best performer while Rectangle 2(EW) is the worst performer in terms of cooling load.

Lighting energy consumption:

-Orientation has negligible effect on lighting energy.
-Square 2 has significantly higher lighting energy consumption compared to other forms.
-More thinner the form the lesser the lighting energy consumption.
-Lighting energy consumption beyond 40% WWR becomes nearly constant.

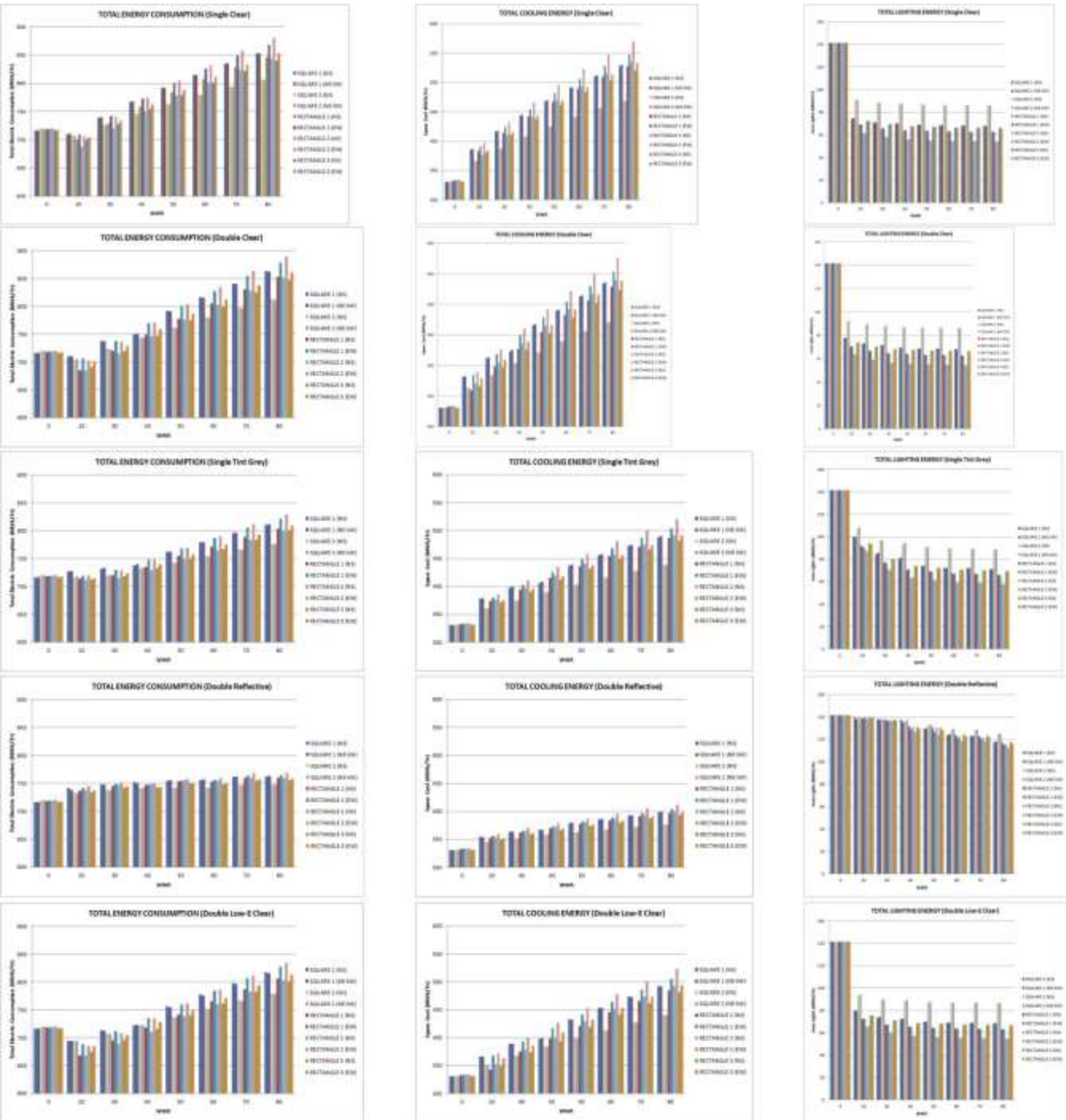


Figure 27: Simulation of WWR vs. Building Orientation based on different glazing types

5.2.4. Analysis of Symmetric WWR vs. Asymmetric WWR

Table 4: Distribution of asymmetric WWR on different orientations

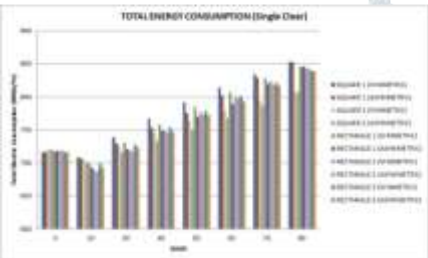
BUILDING TYPE	WWR	NORTH (%)	SOUTH (%)	EAST (%)	WEST (%)
SQUARE 1,2 (1:1)	20%	30	30	10	10
	30%	45	45	15	15
	40%	60	60	20	20
	50%	75	75	25	25
	60%	80	80	40	40
	70%	80	80	60	60
	80%	80	80	80	80

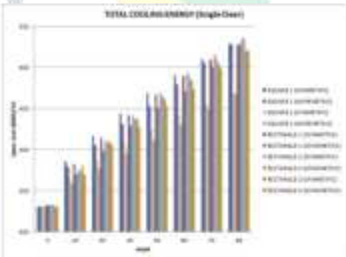
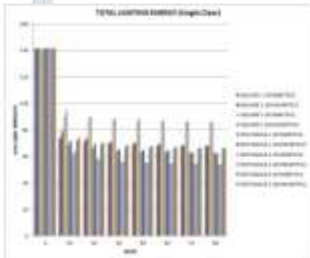
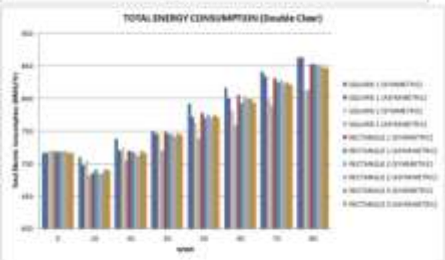
BUILDING TYPE	WWR	NORTH (%)	SOUTH (%)	EAST (%)	WEST (%)
RECTANGLE 1 (1:2)	20%	25	25	10	10
	30%	40	40	10	10
	40%	50	50	20	20
	50%	65	65	20	20
	60%	80	80	20	20
	70%	80	80	50	50
	80%	80	80	80	80

BUILDING TYPE	WWR	NORTH (%)	SOUTH (%)	EAST (%)	WEST (%)
RECTANGLE 2 (1:3)	20%	23.4	23.4	10	10
	30%	34.3	34.3	17	17
	40%	46.7	46.7	20	20
	50%	57	57	29	29
	60%	68	68	36	36
	70%	80	80	40	40
	80%	80	80	80	80

BUILDING TYPE	WWR	NORTH (%)	SOUTH (%)	EAST (%)	WEST (%)
RECTANGLE 3 (2:3)	20%	25	25	12.5	12.5
	30%	38	38	18	18
	40%	50	50	25	25
	50%	60	60	35	35
	60%	75	75	37.5	37.5
	70%	80	80	55	55
	80%	80	80	80	80

Window to wall ratio distribution is increased for North-South orientation and compared with symmetric distribution of WWR for the same WWR to analyses the energy consumption.



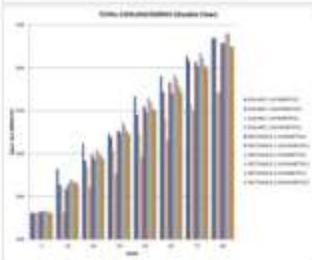
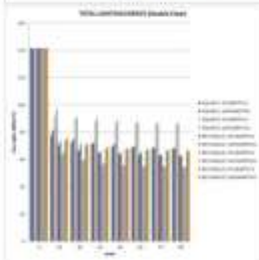



Figure 28: Simulation of symmetric WWR vs. asymmetric WWR based on different glazing types

Observations:

Total energy consumption:

-Slight reduction on energy consumption can be observed after application of asymmetric WWR.
-Best performance is given by rectangle 2 with 20% WWR and low-e glazing. For double reflective glazing asymmetric WWR has negligible effect.
-Single and double clear glazing's are more effected by asymmetric WWR than any other type of glazing.

Cooling energy consumption:

-Reduction in cooling energy can be observed after application of asymmetric WWR.
-Reduction of cooling energy depends on difference between WWR in north-south and east-west window orientations. North-south should have more WWR and east- west should have less WWR.

Lighting energy consumption

-Lighting energy consumption increases slightly with application of asymmetric windows.

5.2.5. Analysis of Shading vs. No Shading

A horizontal Shading device has been added to window to study the effect of shading on energy consumption. The shading has been added so that it can shade the window the most during the hottest time of the day for the particular orientation of the window. The calculations for shading device are shown in Figure 29 and Table 5.

Table 5: Shading device calculations

NORTH WALL

DATE	JULY	
TIME	09:00	16:00
HSA	73.6	-73.1
VSA	74.1	68.2

SOUTH WALL

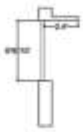
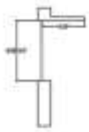
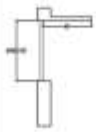
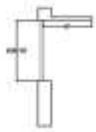
DATE	MARCH	
TIME	09:00	16:00
HSA	-67.3	69.9
VSA	60.9	59.4

EAST WALL

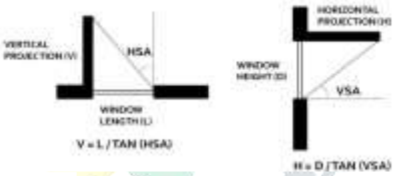
DATE	MARCH
TIME	09:30
HSA	22.7
VSA	44.7

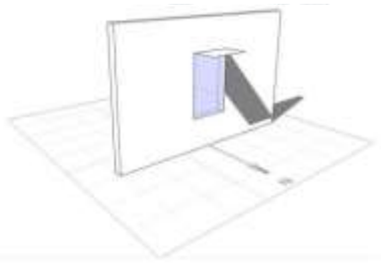
WEST WALL

DATE	MARCH
TIME	15:00
HSA	-20.1
VSA	47.1

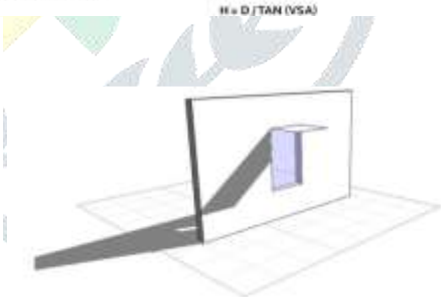
ORIENTATION	NORTH	SOUTH	EAST	WEST
SHADOW ANGLES	VSA = 68.2	VSA = 59.4	VSA = 44.7	VSA = 47.1
SHADING DEVICES	H = 2.4'	H = 3.6'	H = 6'	H = 6'
STRATEGIES				

WINDOW LENGTH, L= 4'
WINDOW HEIGHT, D = 6', 8', 10'

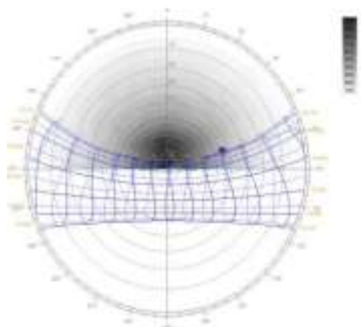


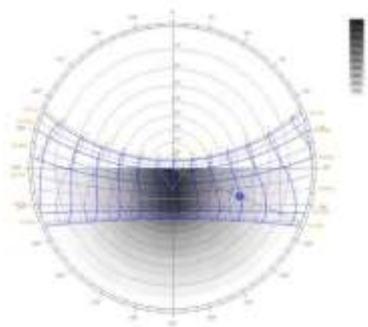


NORTH WINDOW - 4' X 6'



SOUTH WINDOW - 4' X 6'





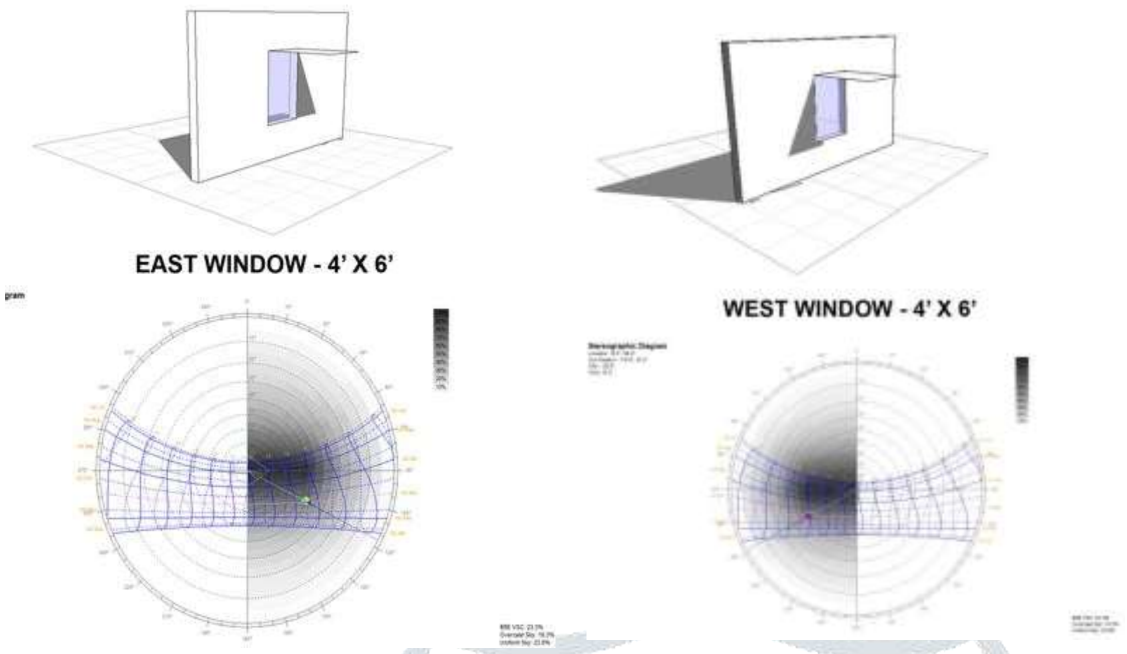


Figure 29: Shading percentages for different orientations

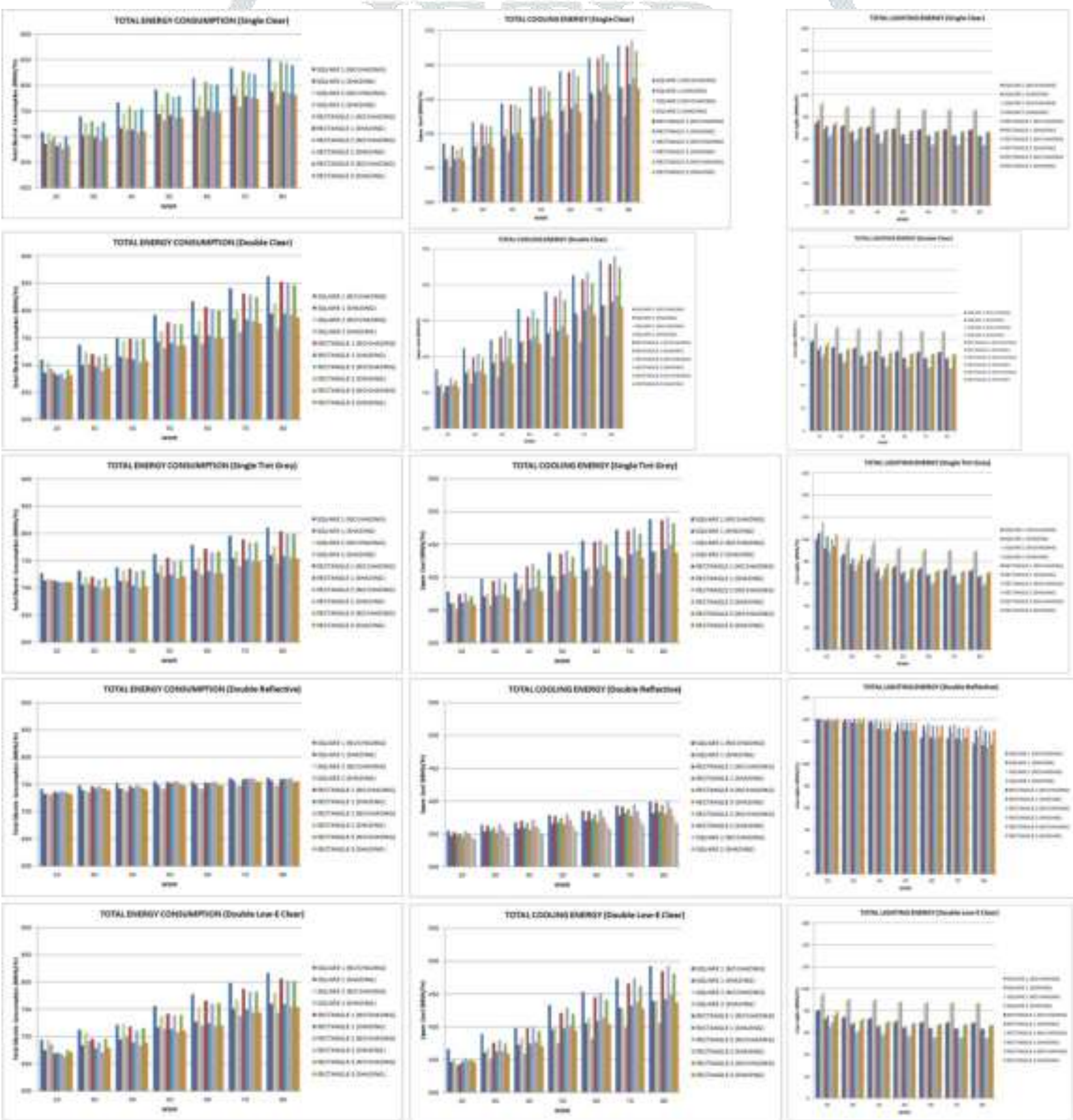


Figure 30: Simulation of No Shading vs. Shading based on different glazing types

Observations:
Total energy consumption:

-Significant reduction in energy consumption can be observed after application of shading devices.
-With rising WWR energy savings due to shading increases.
-For double reflective glazing shading has negligible effect.
-Shaded forms consume almost the same energy regardless of their forms.

Cooling energy consumption:

-Significant reduction in cooling energy can be observed after application of shading.
-Shaded forms have less difference in cooling energy consumption than unshaded forms.

Lighting energy consumption:

-Lighting energy consumption increases very slightly after application of shading.
-Lighting energy consumption has negligible effect for double reflective glazing.

5.2.6. Analysis of WWR vs. Window Size and Position

To determine the effect of window size and position three different window sizes were selected and varied by different positions on the wall. The position of the window is changed from high, middle to low. The models are tested only on single clear glazing.

Table 10: Details of window sizes

WIDTH	HEIGHT	SILL LEVEL		
4'	5'	LOW= 0'	MID = 2.5'	HIGH = 5'
4'	7.5'	LOW= 0'		HIGH = 2.5'
4'	10'	LOW= 0'		

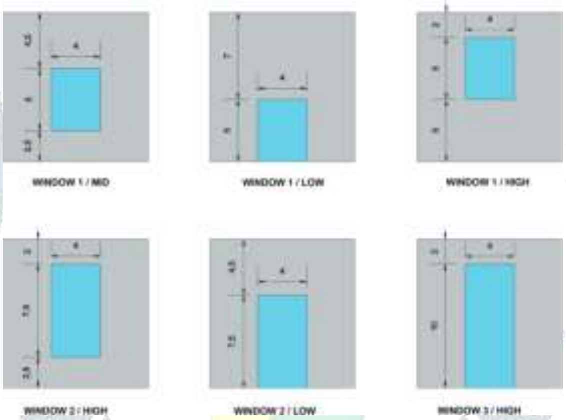
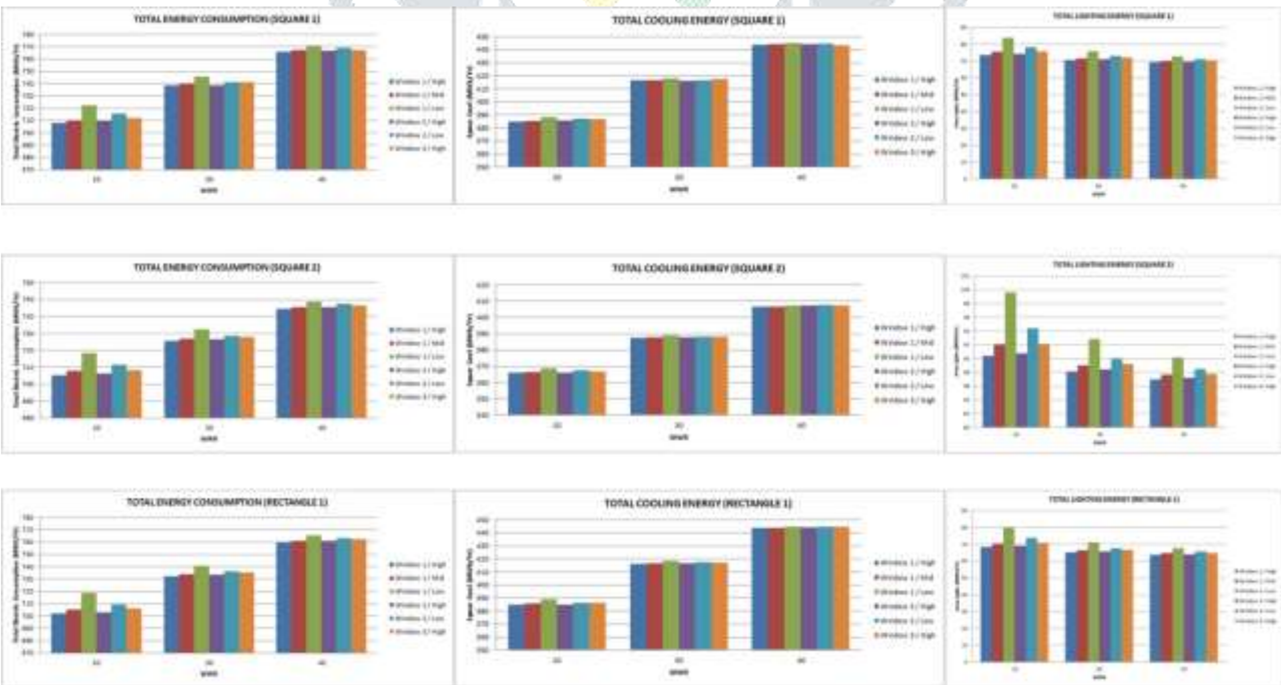


Figure 31: Elevations of windows to be analyzed



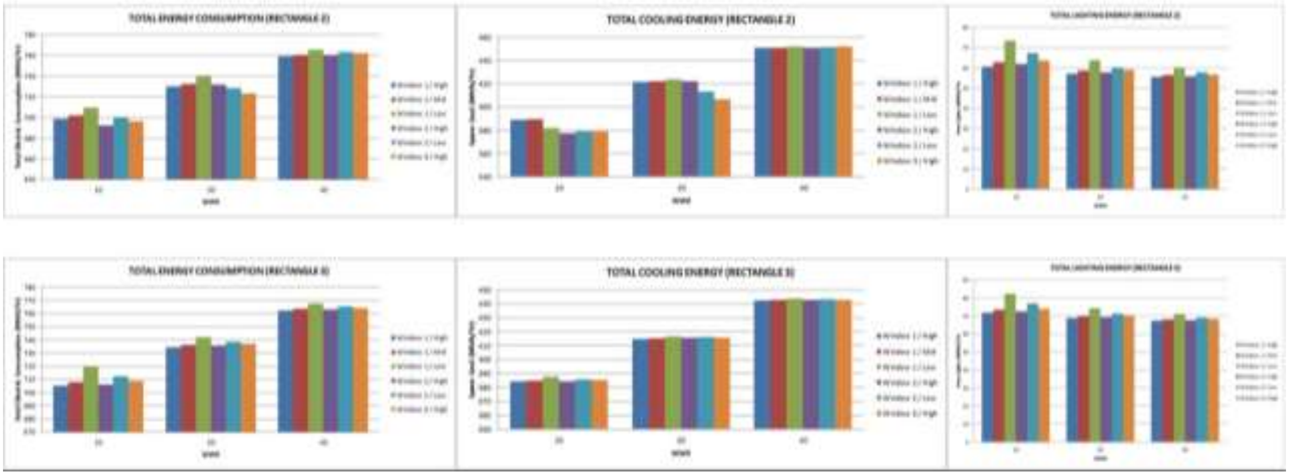


Figure 32: Simulation of WWR vs. Window size & Position based different forms

Observations:

Total energy consumption:

-Energy consumption varies with position of windows.
-High sill windows are more efficient than low sill windows in terms of energy conservation.
-Window 2 / high is found to be the most efficient for energy conservation
-For thinner rectangular forms the impact of window position is more than square forms.

Cooling energy consumption:

-Cooling load is only slightly impacted by window position and size.
-Only for rectangle 2 cooling load seems to be effected by window position.

Lighting energy consumption:

-Lighting load varies with position of windows.
-Windows with high sill are more efficient than windows with low sill in terms of lighting load.

VI. CONCLUSION

6.1. Overall Recommendations

6.1.1. Analysis of WWR vs. Glazing Types

-Best performance in terms of energy conservation is found at 20% wwr.
-Best glazing typology for energy conservation is found to be double low-e glazing.
-Cooling load rises with rising wwr but lighting load does not decreases at the same rate. This suggests that beyond the point where lighting load becomes constant there is no benefit towards energy conservation. Hence, beyond 40% wwr there is no benefit towards energy conservation.
-Since, low-e is a special type of glass with relatively low SHGC and relatively high VLT it performs the best till 40% wwr. Beyond this double reflective glass with lowest SHGC becomes the best performer. This proves that till 40% wwr reduction in lighting load by low-e glass overshadows the reduction in cooling load by double-reflective glass.
- Clear glazing's are acceptable upto 20%-30% wwr.

6.1.2. Analysis of WWR vs. Building Orientation

-Orientation has negligible effect on square form in terms of cooling, lighting and overall energy consumption.
-Energy consumption in thinner rectangle is more effected by orientation. Although lighting load has no impact on orientation of rectangles.
-For wwr upto 40% rectangle 2 (ns) is the best option while for wwr beyond 40% square 2 is the best option.
-Overall rectangle 2 facing ns with 20% wwr and low-e glazing is the most energy efficient option.

6.1.3. Analysis of Symmetric WWR vs. Asymmetric WWR

-Total energy consumption has only slight impact for asymmetric wwr.
-Reduction of energy depends on difference between wwr in north-south and east- west window orientations. North-south should have more wwr and east-west should have less wwr.
-Best performance is given by rectangle 2 with 20% wwr and low-e glazing.
-Lighting energy consumption increases slightly with application of asymmetric windows.

6.1.5. Analysis of shading vs. No Shading

-Shading is observed to have the most impact on energy reduction.
-For clear glazing's shading can nullify the effect of form beyond 50% wwr.

-Impact of shading on energy conservation rises with rise in wwr. .
-Shaded forms have little difference in their cooling load as compared to unshaded forms.
-Impact of shading on double reflective glazing is the minimum.
-Shading does not increases the lighting load to a significant amount suggesting there is little difference in available lux levels for shaded and unshaded forms.

6.1.6. Analysis of WWR vs. Window Size and Position

-Windows with high sill are more efficient than windows with low sill in terms of energy conservation.
-For thinner rectangular forms the impact of window position is more than square forms.
-Cooling load is only slightly impacted by window position and size.
-Windows with high sill are more efficient than windows with low sill in terms of lighting load.

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