Energy Optimization in Commercial Building in Indian Tropical-Humid Climate

(Study based in modification in existing building)

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ABSTRACT- The commercial spaces that are built before increasing awareness of energy savings in the buildings, consumes more energy especially for cooling & artificial lighting the office space. This research dissertation is a case study type, where significance of energy reduction inputs in building envelope are explained and demonstrated with help of a case study project in Pune, India. *Thus the research tends to demonstrate that modifying the building envelope to an effective thermal performing solution, results in energy savings.*

The project study specifically chosen is a conventional non-energy efficient commercial day time running building with air conditioning unit for cooling the office space (no heating source), highlighting the existing practice for many of the buildings in the region. The building envelope components (Roof, external wall, glazing, shading) being crucial for providing thermally comfort environment as well as architectural beautification of building are modified through changes in the specification for energy savings, keeping the architectural design , ventilation , air conditioning & lighting system the same. The research helps the decision makers to make an informed decision considering the energy saving measures as well as its impact on the financial structure. Thus it also gives the client an opportunity for increasing the rent cost on the usable workspace.

The demand for commercial space is increasing in India due to expanding & upcoming companies, thus increasing the energy demand for running the building. Although energy saving from efficient ventilation & cooling units, low energy consuming lighting system, automatic control censors have significantly reduced the energy consumption, but an effective building envelope plans to reduce energy over the long term life of the building.

Thus the research analyses the impact of considered building envelope components and justifies the reason for the energy reduction. It finally concludes with recommendation for the best case for modified scenario and proposes the concept of High performance building for future work.

KEYWORDS- BUILDING ENVELOPE, COMMERCIAL BUILDING, ENERGY OPTIMIZATION, ENERGY SIMULATION , IJSER RESEARCH PAPER, INDIA TROPICAL CLIMATE , THERMAL PERFORMANCE

ABBREVIATIONS

GDP- Gross Domestic Product

IEA-International energy agency

IES-International Energy Agency

EPI-Energy Performance Index

BEE-Bureau of Energy Efficiency

BIS- Bureau of Indian standards

ECBC-Energy Conservation Building Code

NBC-National Building Code (India)

CEA-Central Electricity Authority

EPS-Energy Power Survey

HVAC- Heating Ventilation & Air Conditioning

GRIHA- Green Rating for Integrated Habitat Assessment

ASHRAE- American Society of Heating, Refrigerating, and Air-Conditioning Engineers

ISHRAE- Indian Society of Heating, Refrigerating, and Air-Conditioning Engineers

TERI – The Energy & Resource Institute, New Delhi.

CPWD- Central Public Works Department

COP- Coefficient of Performance

WWR- Window to Wall Ratio

AHU- Air handling Unit

SC- Shading coefficient

VLT- Visible Light transmission

XPS Insulation- Extruded Polystyrene

RCC- Reinforced Cement Concrete

CAD- Computer Aided Design

UNITS AND EQUATIONS

- Units
  - Millimetre – mm
  - Meter – m
  - Tonne of refrigeration- TR
  - Sq.m – square meter
  - cfm – cubic feet per minute
  - W/m^2 K- Watt per meter square Kelvin (U value)
  - m^2 K/ W - meter square Kelvin per Watt (R value)
  - Illumination – lux
  - Energy consumption kWh- Kilowatt hour

- EQUATIONS
  - R_T (thermal resistance) =l (thickness) /k (thermal conductivity)
  - $R_T = R_i + R_1 + R_2 + \ldots R_N + R_e$
  - $U = 1/R_T$
  - $TPI = (T_{internal} - 30) * 100 / 8$
  - $TPI = (q-46)*2.5$
- Conversions
  - 1 W/(m^2·K) = 0.176 Btu /hour/foot²/°F
  - 1 MBTU = 0.29307 kWh
  - 1 ft = 0.3048 m
  - 1 USD= 70 INR

Table of Contents

1.1 AIM METHODS AND OUTPUT

Chapters	Research AIM	Methods	Output
Introduction	Energy Scenario in Commercial sector buildings Outlining the drivers and background of the dissertation	Desktop study - Journals, Architecture published Studies, Government Data.	Understanding the flow and need for the dissertation The stakeholders benefiting from the dissertation
Indian Building Practice	Overview of Indian Climatic condition and outlining warm & humid climatic condition. Defining energy efficient building standards and codes	Desktop study ECBC (Energy Conservation Building Code) Manual	Geography and Climatic conditions explained that are the background for the research. Performance requirement for baseline building and efficient building practice.
Impact of Solar Passive & Building Envelope Design	Defining the solar passive parameters & Building envelope for existing building for warm-humid climate zones.	Literature review- Research work from Research authors and university.	Energy savings measures through passive design & effective envelope components for warm-Humid climate zone.
Evolution in Energy Efficient Measures	Outlining the changes in the building envelope components (conventional v/s energy efficient solution)	Literature review- Government study reports & case study projects Architectural Journal	Highlighting the changes in building envelope on and increase energy savings. Validating with real projects
Methodology	Describing the climatic condition of the project	Statistics from Green building organisation	Data collection and modelling process used for the study.

	Describing the architectural, building envelope, HVAC & lighting system used for the project Outlining the software and tools used for the study.	Collection of data - Architectural, Civil & Maintenance Data from main contractor & maintenance department. (CAD Drawings & Maintenance word files) eQuest Literature support.	Describing eQuest software and the tools used- basic geometry, converted weather file , building envelope and internal space designing , describing lighting system and daylighting mode, air conditioning and chiller details
Design Scenarios	Outlining the different building envelope scenario & alternate specification for energy reduction	Thermal properties and values for wall & roof layers are drawn from Bureau of Indian Standards. Thermal calculation (MS Excel) Glazing specification from Saint Gobain	The selection of the specification and the impact on energy reduction. The configuration of the layers and the specification & coefficient values- (R, U, SC,VLT)
Energy & Cost Analysis	The energy consumption of the building in different scenario. The cost and payback period associated with each scenario	Simulation results from software- eQUEST (version 3-65) The costing data of the envelope material is drawn from Government rates for construction cost, saint gobain rates for glass (through glazing contractor).	Comparative analysis of the impact on the energy consumption of the building for modified building envelope. The increased cost and payback period for selecting the optimised case.
Conclusion & Scope for future work	Concluding and recommending best case scenario for the project.	Analysis from the dissertation and	Concluding the final results and potential net energy savings from the best case scenarios

	Highlighting the futuristic energy cautious building and components in energy savings.		High performance building concept integrating active, passive and building envelope components.

Table1.1-1 Research aim, Methods & Output

1.2 Energy Scenario in India

India being one of the fastest growing economy in the world, with growing GDP of around 7.7 % annually (Central Statistics Office, 2017) and thus is rapidly increasing its energy requirements. As per India's Twelfth 5 year plan (2012-17), additional capacity of 75,785 MW is required giving a total of 276,000MW to meet the peak demand of energy.

The latest Thirteenth Five year plan (2017-22) states that by 2022, energy deficit will be around 13896 MW (considering 6% GDP growth) & 11909 MW (considering 9% GDP growth)

The Thirteenth Five Year Plan (1 April, 2017 – 31 March, 2022)				
	6% GDP growth		9% GDP growth	
Year	Availability (MWh)	Requirement (MWh)	Availability (MWh)	Requirement (MWh)
2017-2018	151,570	164,801	157,483	169,876
2018-2019	157,806	171,225	165,370	177,716
2019-2020	164,218	177,810	173,706	185,953
2020-2021	170,805	184,557	182,357	194,470
2021-2022	177,571	191,467	191,597	203,506

Figure 1.2-1 Energy Deficit Statistics (13th Five year Plan-CEA, 2017)

One way is to generate and exhaust more natural resource for power generation which is considered important for economic growth, but it is equally important to search energy saving measures which will reduce energy consumption in most efficient way. Currently Building sector is consuming 29% (CEA 2013) and is one of the main energy consuming sector in India.

In past from 1995- 2005-06, 47% of total energy was consumed by building sector (IEA, 2007) with 74% in residential and 26% in commercial sector.(i.e- commercial building consumed around 12% of total national energy)

Although in present times, power consumption in the commercial sector in India is comparatively less than other sectors about 8% (Fig 1.2-2) of total power consumption (CEA 2013), the amount of power consumed has increased.(Fig 1.2-3)

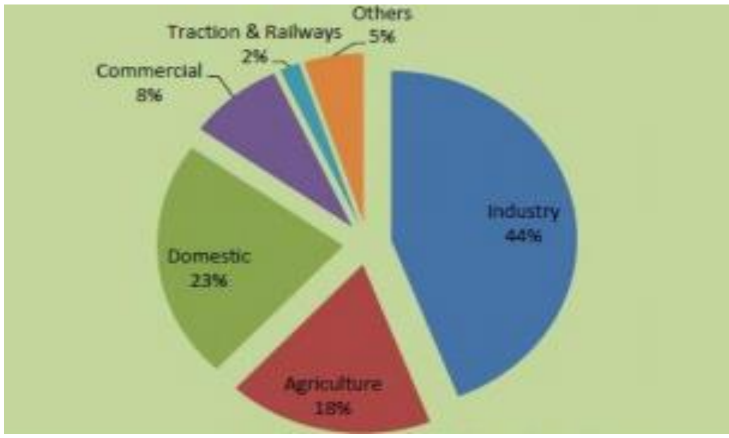
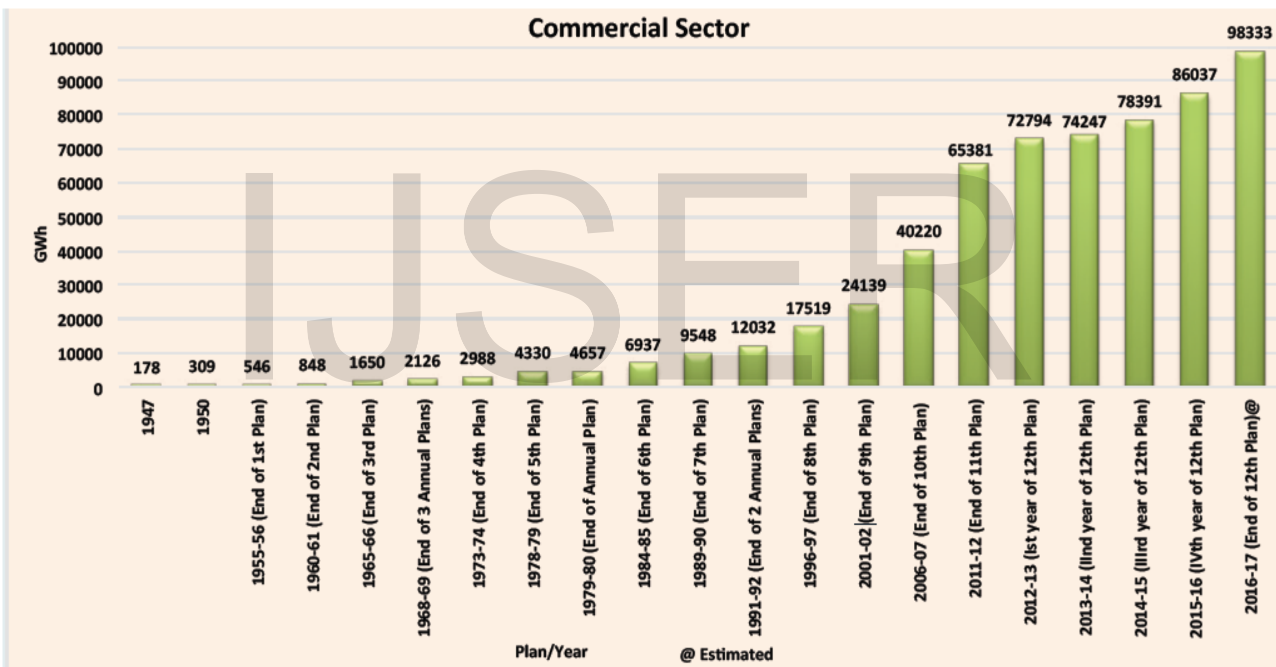


Figure 1.2-2 Power Consumption sector wise (CEA 2013)

Electricity consumption in commercial buildings has grown by average – 9.5% per decade after independence 1947. (CEA, 2017)



Year	1947-50	1950-60	1960-70	1970-80	1980-90	1990-2000	2000-10	2010-17
% Growth	3.18	9.50	11.78	7.15	7.45	8.28	11.47	7.69

Figure 1.2-3 Growth in Electricity consumption in commercial sector (CEA, 2017)

Cooling and lighting load are predominant energy consumption componets, having a combined energy intake of around 72% (almost 3/4th) in tropical region buildings, especially in commercial and public buildings (Figure 1.2-4). Building envelope is directly in link with these 2 factors and thus in tropical climate a balance of increase natural daylight and reduce solar gain is an important aspect.

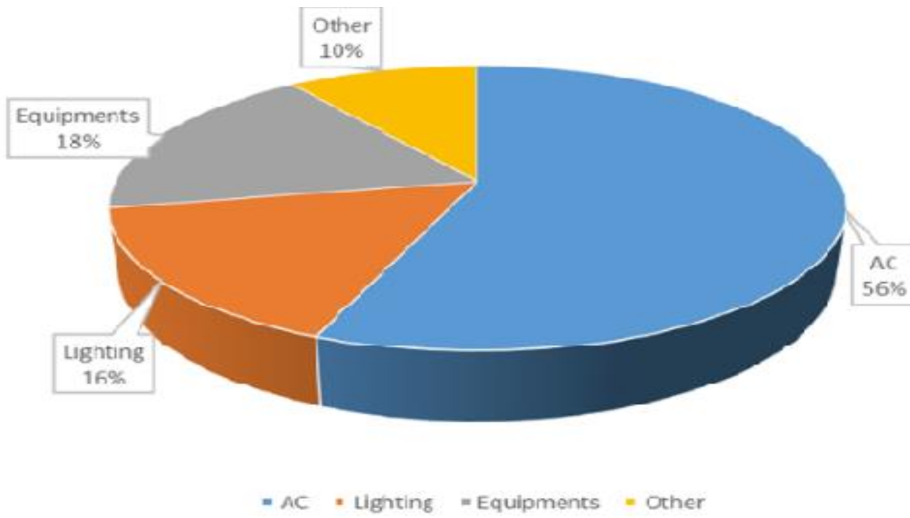


Figure 1.2-4 Typical Commercial building Energy consumption in Tropical & sub- tropical climate (Boukhanouf, 2013)

1.3 Drivers for Research

1.3.1 Past Architecture

According to article by Dr. Satya Srivastava - The Indian Architecture was a combination of Indo-Islamic mixture which was passed from the architecture from countries like Iran, Egypt and Iraq. Well known as *Delhi style of architecture* which had presence of arch and dome and relied heavily on the knowledge and skills of Indian Craftsman in stone work. The construction sector was confined to dwellings, religious worship centres at individual and community level using traditional thermal mass fabric during construction.

With Advent of European colonialism, more commercial and trade buildings began to flourish. The British had a major impact on the Indian buildings which saw architectural shift from Indo-Islamic to British way of architecture (Commercial centres, Schools, Church, Historical Monuments, and Warehouse

A major breakthrough in modern architecture for Indian Construction happened in 1947 just after the Independence. India required an architecture to express their march to economic development which gave rise to design and construction of Golconde which was a dormitory for the ashramites designed by Czech-born architect Antonin Raymond. It was the earliest example of a good reinforced concrete building in India with its detail and feature evolving and adapting through study of Indian Climate and the comfort required for the occupants. The architecture gave a major breakthrough in Building envelope in India as it achieved cross ventilation and sun protection with best use of the building orientation.

Figure 1.3-1 Golconde Architecture

Some of the key architectural features in Building envelope were

- Concrete Roof tiles creating an Insulation Zone
- It had a sliding panel made of staggered strip of teak wood allowing ventilation while maintaining privacy
- Concrete louvers for constant air circulation between north and south façade.
- Pools and Garden in the vicinity for creating ambient air and cool microclimate.

The Indian architecture is based on controlling and utilizing the energy of sun which is available in large part of Indian sub-continent (D Vyas, 2005). Low storey buildings were dominant in past, thus the heat gain through the roof had significant effect that the wall.

The thermal environment of traditional houses is comparatively better than modern structures due to presence of solar passive features- courtyards, thick walls, tilted roof and natural ventilation. Minimum 10-20% can be saved in the native architecture compared with contemporary structures. (Indian journal of Science & Technology, 2017).Then came the era of modernisation, after the use of Metals and glass in buildings in western countries (Europe and America), the trend started in India too. First building in India that had curtain wall was Le Meridian Hotel in New Delhi which was constructed in early 80's for Asian Games (MGS, Architecture, 2006). Later, architectural curtail walling showed an active growth in late 90's- early 2000 with a boom in Information technology sector which gave rise to major real estate developers like –DLF, Hiranandani, Unitech, Raheja. With rise in latest technology and design which were available in market, 15- 20 major curtain wall fabricators took big glazing jobs and changed the use of float glass sheet to architectural use in buildings. (Window & Façade Magazine, Sept-2017)

Figure 1.3-2 First Glass curtain wall Building in India

1.3.2 Current Commercial buildings in India

Currently, approximately 659 million m² spaces is used as commercial space and in 2030, it is estimated that it would increase to 1,900 million m² and by then more than 60% of the commercial built space would be air conditioned.(Kumar & Satish, 2011).

Currently, major demand for office space is in Information technology (IT) service sector as the economy is shifting from central business districts to secondary service sectors. i.e IT parks & Offices.

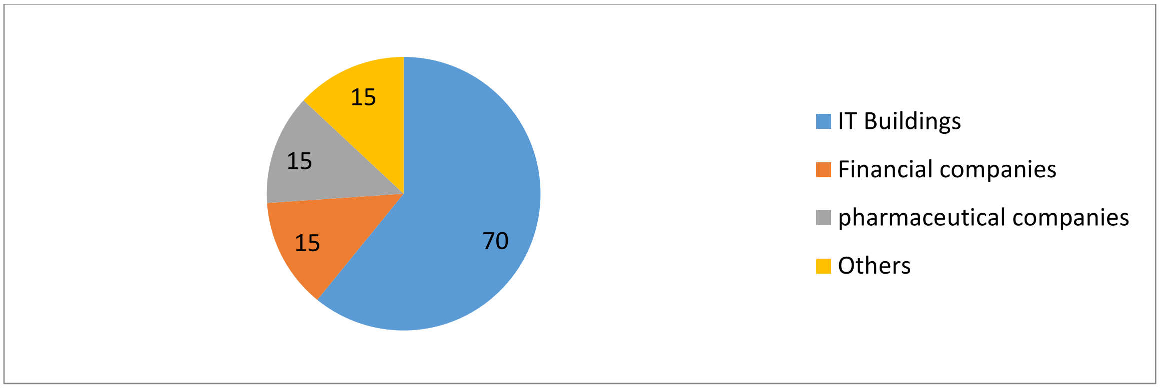


Figure 1.3-3 Sector wise Energy consumption in commercial office (CBRE, Indian Market overview, 2015)

Thus with rise in demand for IT parks and influx of (Multi- national company) MNC buildings, it has boosted demand for façade and fenestration, especially glass clad buildings. Overall, demand for Grade A office space in the top seven cities of the country rose 18% to touch an all-time high 3.5 million square meter in 2015, compared to a year earlier, property consultancy firm CBRE said in its India Office Market View report.

With recent global evolution in façade and fenestration, Indian market too has undergone a drastic changes. Recently Analysis done by ABK Consulting shows that Curtain wall and fenestration market in India is about 1.75 billion USD with higher use of aluminium products, marking a shift from wood to aluminium in façade market.

A report posted in Window and façade Magazine showed that Indian window and door market was around 0.19 Billion USD in year 2013-14 and as per Report by Ken Research, it is expected to reach 0.22 Billion USD by 2020.

Along with the rise in façade industry especially use of glass, energy efficient buildings became the need of the hour to decrease energy consumption through building envelope.

Most of the commercial buildings currently have energy performance index of 200 to 400 kWh/ sq m/ year as compared to similar buildings in North America and Europe which have an EPI of less than 150 kWh/ sqm/ year. Energy conscious building design has shown to reduce EPI to 100-150 kWh/sqm/year (UNDP & GEF, 2011). As per BEE, there is potential of 30-40 % energy savings in the existing building.

1.4 Current Practice

1.4.1 Energy Efficient Building Standards

ASHRAE being the global recognised standard in energy efficient practice, has a dominant role in India.

Standard 90.1- Energy Efficiency for Commercial Buildings & Standard 189.1- Green High Performing Commercial Buildings are used in meeting the requirement for designing energy efficient buildings.

In May 2007, Ministry of Power and Bureau of energy efficiency (BEE) launched **ECBC** for Voluntary adoption in the country. It is based on ASHRAE 90.1 and guidelines from NBC. ECBC states the minimum required performance criteria for different elements in building envelope and HVAC system for 5 climate zones (as per NBC). As of 2016, out of 28 states, 10 states have made ECBC mandatory in commercial buildings, while another 10 are in the stage of making it mandatory. As Per computer simulation model, ECBC Compliant buildings can save 20 to 40% electricity consumption as compared to current existing building Fig (1.4-1). As per report by BEE (Saurabh Diddi, 2017), for year 2017-18, mandatory enforcement of ECBC has a technical potential of yielding a savings of 4.3 billion kWh of energy. Below is ECBC impact on energy savings in different Indian climate.

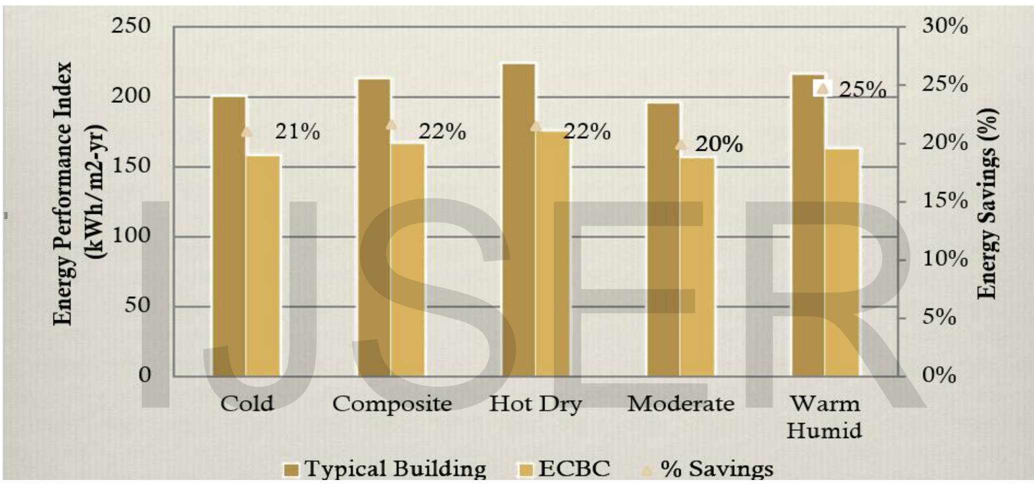


Figure 1.4-1 ECBC Compliant Buildings Energy Savings (BEE, 2017)

1.4.2 Energy efficient Rating system

- **LEED INDIA**, which is one of the frequently associated rating system based on 100 base points for new construction with 4 certification criteria
  - Certified 40–49 points
  - Silver 50–59 points
  - Gold 60–79 points
  - Platinum 80 points & above

LEED INDIA-2011 bestows points as per whole building energy simulation in accordance with ASHRAE Appendix G 90.1-2007 using computer simulation model.

The existing building renovations with 8% energy savings from base case gives 1 point and with rise in every 2% adds 1 more point. The maximum gained points can be 19, with 44% energy reduction.

- **GRIHA –** Launched in 2007 in association with ECBC consisting of total 100 points which are divided among 34 criterion. Some of them are mandatory while others are partly or applicable.
  It consists of 5 rating certification
  1 star- 50-60 points
  2 star- 61-70 points
  3 star- 71-80 points
  4 star- 81-90 points
  5 star- 91-100points

  The criterion which are important for energy conservation through building envelope are-
  - Criterion 13- Optimize building design to reduce conventional energy demand- Mandatory.
    Adequate daylighting in this criterion enables 2 points.
  - Optimize energy performance of building within specified comfort limits-Partly mandatory.
    It ensures that the building meets the thermal comfort as per NBC 2005 and the energy reduction through simulation is under 10-40% less than benchmark enabling 16 points.
- **BEE**
  Launched in 2009, this is one of the basic rating system which relies on energy performance index (EPI) for rating the building from 1 star to 5 star.
  Since it is evolved considering Indian climate, for different sub climate zones (Hot, humid, composite), the requirement varies accordingly.

Composite	
EPI(Kwh/sqm/year)	**Star Label**
190-165	1 Star
165-140	2 Star
140-115	3 Star
115-90	4 Star
Below 90	5 Star
Warm and Humid	
EPI(Kwh/sqm/year)	**Star Label**
200-175	1 Star
175-150	2 Star
150-125	3 Star
125-100	4 Star
Below 100	5 Star
Hot and Dry	
EPI(Kwh/sqm/year)	**Star Label**
180-155	1 Star
155-130	2 Star
130-105	3 Star
105-80	4 Star
Below 80	5 Star

Table 1.4-2 EPI Requirement for commercial building (more than 50% conditioned) (BEE 2009)

1.5 Research Boundaries and Limitation

The research project is a mid-rise commercial building based in Pune, India.

In order to consider energy saving measures for commercial buildings, various components from envelope to HVAC system to elevators and other mechanical-electrical components can be considered and efficiently modified for reducing energy output. This dissertation focuses solely on **Building envelope components** for reducing final energy output, keeping all other building service and system the same.

The architectural modification like changes in orientation, WWR etc is not feasible for the existing project, thus only the feasible modification for envelope is targeted.

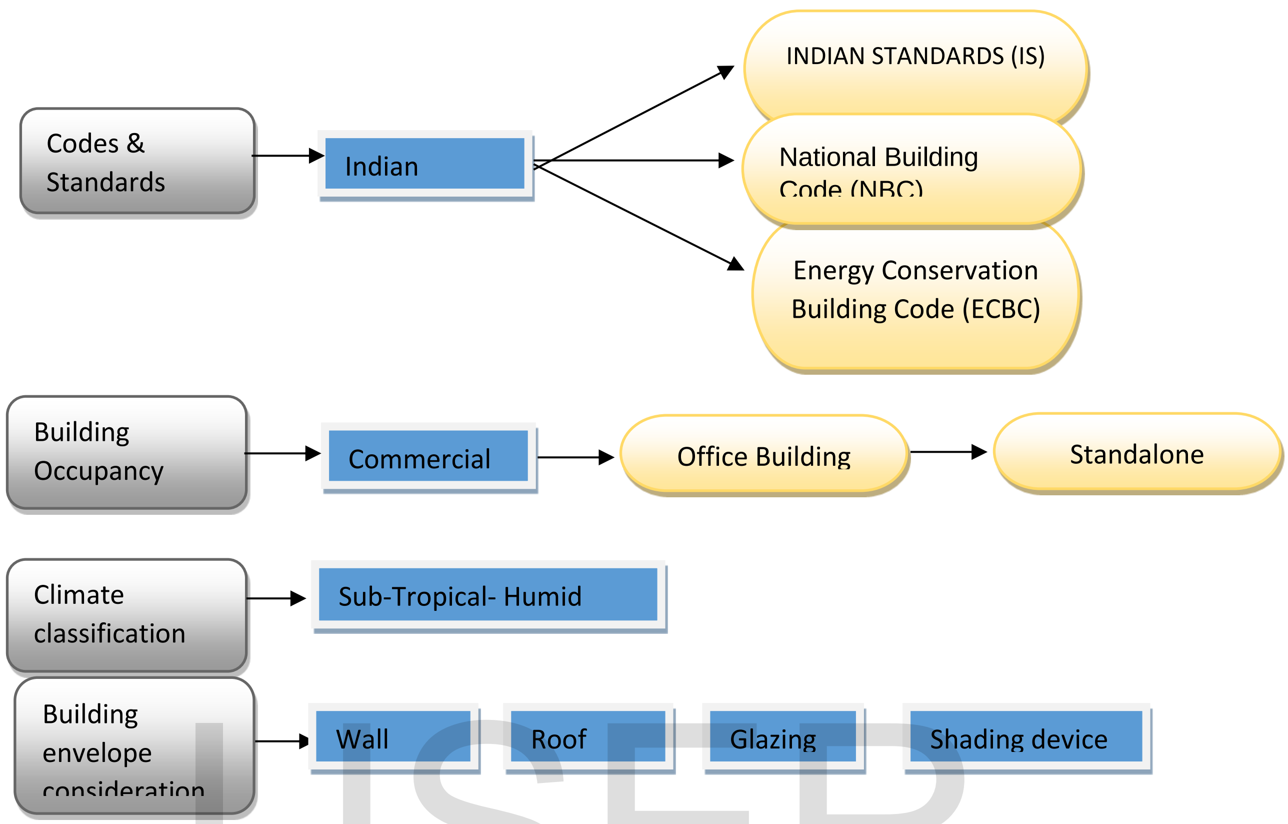


Figure 1.5-1 Research Boundaries

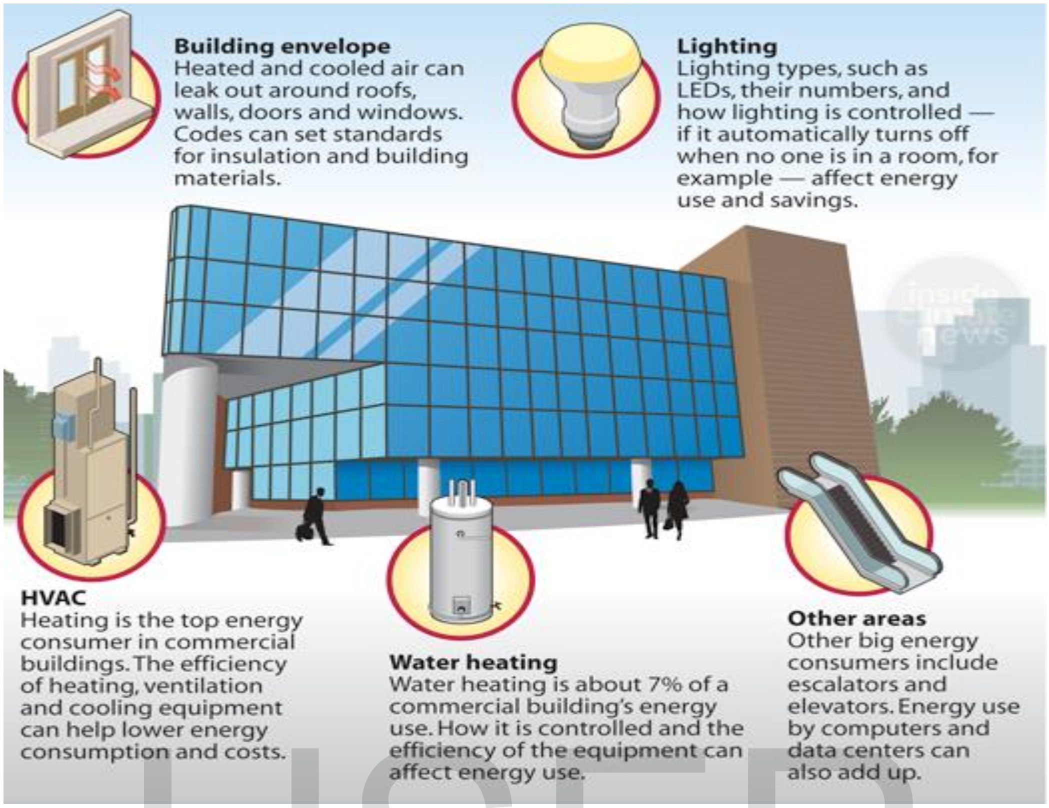


Figure 1.5-2 Elements for Increasing Building Energy Efficiency (ASHRAE, Department of Energy)

1.6 Deliverables and contribution to knowledge

The dissertation considers energy saving measures in commercial building in India. **The dissertation serves as an informed guide for energy savings in re-furbished buildings and creating awareness for energy savings in India.**

It has impact on below group-

A. **Employees**- Providing comfort from the hot and humid climate to increase employee's productivity.
B. **Client** – Reduction in the operational cost of the building i.e- Reduction in cooling & lighting load. Thus this gives opportunity for the client/developer to also increase the rent of the usable space.
C. **Architect** – Maintaining the same architectural intent of the building, along with better thermal performance of the building.
D. **Government** – Promotion and adoption of Indian efficient standards for building envelope and energy saving impact associated with it.

The dissertation streamlines different energy cautious envelope measures to an existing building which imparts knowledge to below stakeholders

A. **Architects and Engineer**- A better technically informed measures and recognised envelope specifications and standards for modification in existing conventional building.
B. **Client**- The impact of building envelope on the energy savings of the building which will help them make correct decision for existing building modification. The return of investment analysis helps them to decide commercially viable solution.
C. **Government –** A reduction in power consumption and thus narrowing the energy deficit gap.

2. Energy efficient building practice

2.1 Indian Climate Overview

India lies between 8 ^{0}N and 37 ^{0} N latitudes. The Tropic of Cancer passes through the middle of India, thus making the southern half of India in the Torrid Zone and the northern half in the Temperate Zone (Indian Meteorological Department). According to (ASHRAE 90.1). India comes under Climatic Zone-1, mostly hot & dry or hot and humid all year.

The standard required for the building Envelope depends on the region where the construction is undertaken. According to Dr. Winfried Heusler (Schueco International) the most important function of façade in India above all the performance parameter is ensuring weather tightness and solar protection.

Indian climate is further sub categorized in accordance to temperature and relative humidity which helps in designing of building technology system and envelope in accordance to outside weather.

Climate	Mean Monthly temperature (ºC)	Relative Humidity
Hot and Dry	>30	<55
Warm and humid	>30	>55
Moderate	25-30	<75
Cold & Cloudy	<25	>55
Composite	This applies, when six months or more do not fall within any of the above categories.	

Table 2.1-1 Climate zone classification

Below is the Climatic map of India which highlights that the central part experiences a composite climate while hot and dry region includes the Western '**Thar Desert'** belt. The warm and humid climate is observed in long stretch of coastal areas in east and west which further extends to north east India. The Himalayas covering the north have a cold temperature zone.

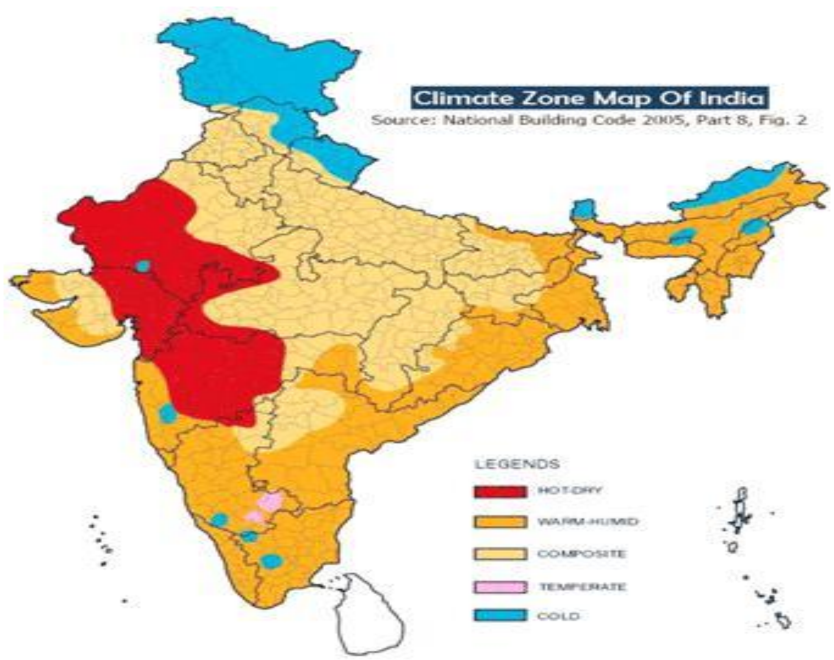


Figure 2.1-1 Climatic Map of India (NBC, 2005)

2.2 Warm & Humid Climate

As per climatic map of India, a total of 16 out of 29 states experiences warm and humid climate.

Since the dissertation is in relation to commercial building in Warm & Humid climate which is categorised as per ECBC as-

- Temperature is moderately high during day & night with very high humidity and rainfall.
- The diffuse fraction of solar radiation is quite high due to cloud cover, and the radiation can be intense on clear days. The dissipation of the accumulated heat from the earth to the night sky is generally marginal due to the presence of clouds. Hence, the diurnal variation in temperature is quite low.
- Calm to very high winds from prevailing wind direction
- Long monsoon period with heavy rain

Below are the temperature, humidity and rainfall data observed in warm and humid climate zone.

Summer Mid day Temp (°C)	Summer Night Temp (°C)	Winter Mid day Temp (°C)	Winter Night Temp (°C)	Humidity	Rainfall
30-35	25-30	25-30	20-25	70-90%	More than 1200 mm/year

Table 2.2-1 Warm & Humid climatic Data (Krishnan, 2001)

2.3 Indian Requirement for Energy Efficient Building

The ECBC code is based on ASHRAE 90:1 and with help of reference documents/ standards from National Building Code (NBC-2005) considering Indian climatic conditions. The code is applicable to buildings have connected load of 500KW , generally buildings having conditioned area of 1000m^2 or more falls under the ECBC compliance buildings.

Measures	Wall	Roof	Window
Minimize conduction losses	Use insulation with low U-factor	Use insulation with low U-factor	Use low conductivity gasses in the cavity units. In frames, using low conductivity material like vinyl or fiberglass instead of aluminium.
Minimize Convection loss	Reduce air leakage using a continuous air barrier system	Reduce air leakage using a continuous air barrier system	Reduce infiltration loss-Use prefabricated windows and seal the joints between windows and walls. Weather stripping and caulking. Reducing convection loss-Optimally spacing gas filled gaps .
Minimize moisture penetration	Reduce water infiltration: Use continuous drainage plane. Reduce air transported moisture: Use continuous air barrier. Reduce moisture diffusion into the wall: use vapour barrier/retarder	For water and air tight roof: Continuous air barrier Reduce moisture diffusion: vapour barrier/retarder	Use prefabricated windows and seal the joints between windows and walls.
Minimize radiation loss	Use light coloured coating with high reflectance	Use light coloured coating with high reflectance	Use glazing with low solar heat gain coefficient (SHGC) and use shading device.

Table 2.2-2 Measures for energy efficient buildings (BEE Tip sheet, 2009)

2.3.1 Compliance Approach-

I. Prescriptive Method-

The ECBC code sets a prescriptive minimum requirement for building envelope components. Compliance can be achieved by meeting the set requirements for each individual component. The code also provides trade –off option between different building envelope components i.e- using higher wall insulation allows less stringent U-factor requirement for windows, vice versa). Trade-offs is only permitted between building envelope components, i.e- trade off should not be between HVAC system and natural lightning.

II. Whole Building Performance Method-

Energy Simulation Software is necessary to show ECBC compliance via this method. (Code does not state any official compliance simulation tools but the simulation carried is according to ASHRAE Model) . The code involves developing computer model of proposed design and comparing its energy consumption to standard design (represents upper limit of energy use). Code compliance will be achieved if energy use in proposed is no greater than energy used in standard design.

2.3.2 Mandatory Requirements

a) Air Leakage-

Air leakage for glazed swinging entrance doors and revolving doors shall not exceed 1.0 cfm. Air leakage for other fenestration and doors shall not exceed 0.4 cfm.

b) U Factor-

Calculation of U factor for fenestration system is required to be determined in accordance with ISO- 15099.

c) SHGC-

ECBC requires that SHGC should be determined in accordance with ISO-15099 by an accredited independent laboratory and certified by manufacturer or other responsible party.

2.3.3 Prescriptive Requirement – Building Envelope

Below are the minimum requirement for different building envelope components to comply through prescriptive method.

I. ROOFS / WALLS-

Depending on the working hours & use of the building, the U value requirements are set as per ECBC-2007 Standards. The requirement for roofs & walls can be achieved by below ways-

- Minimum required R-value of the insulation
- Assembly U-factor that meets the maximum U-factor criterion for thermal performance

Climate Zone	**24-Hour use buildings Hospitals, Hotels, Call Centers etc.**		**Daytime use buildings Other Building Types**	
	Maximum U-factor of the overall assembly (W/m2·K)	Minimum R-value of insulation alone (m2·K/W)	Maximum U-factor of the overall assembly (W/m2·K)	Minimum R-value of insulation alone (m2·K/W)
Composite	U-0.261	R-3.5	U-0.409	R-2.1
Hot and Dry	U-0.261	R-3.5	U-0.409	R-2.1

Warm and Humid	U-0.261	R-3.5	U-0.409	R-2.1
Moderate	U-0.409	R-2.1	U-0.409	R-2.1
Cold	U-0.261	R-3.5	U-0.409	R-2.1

Table 2.3-2 ECBC Prescriptive requirement for Roof

Climate Zone	**24-Hour use buildings Hospitals, Hotels, Call Centers etc.**		**Daytime use buildings Other Building Types**	
	Maximum U-factor of the overall assembly (W/m2·K)	Minimum R-value of insulation alone (m2·K/W)	Maximum U-factor of the overall assembly (W/m2·K)	Minimum R-value of insulation alone (m2·K/W)
Composite	U-0.440	R-2.10	U-0.440	R-2.10
Hot and Dry	U-0.440	R-2.10	U-0.440	R-2.10
Warm and Humid	U-0.440	R-2.10	U-0.440	R-2.10
Moderate	U-0.440	R-2.10	U-0.440	R-2.10
Cold	U-0.369	R-2.20	U-0.352	R-2.35

Table 2.3-2 ECBC Prescriptive requirement for Opaque Wall

II. Cool Roofs-

These are roofs covered with a reflective coating that has a high emissivity property that is very effective in reflecting the sun's energy away from the roof surface. These cool roofs are known to stay 10°C to 16°C cooler than a normal roof under a hot summer sun. In India- lime coats, white tiles grouted with white cement, special paints, etc. are used as cool roofing materials.

Requirement-

Roofs with slopes less than 20° shall have an initial solar reflectance of no less than 0.70 and an initial emittance no less than 0.75. Solar reflectance shall be determined in accordance with ASTM E 903-96 and emittance shall be determined in accordance with ASTM E408-71 (RA 1996).

III. Vertical Fenestration-

As per ECBC, the vertical fenestration is limited to maximum 60% of gross wall area. Below are the requirements of ECBC for vertical fenestration depending upon Window to wall ratio (WWR).

		WWR≤40%	**40% <WWR≤60%**
Climate	Maximum U-factor	Maximum SHGC	Maximum SHGC
Composite	3.30	0.25	0.20
Hot and Dry	3.30	0.25	0.20

Warm and Humid	3.30	0.25	0.20
Moderate	6.90	0.40	0.30

Table 2.3-3 ECBC Prescriptive requirement for fenestration

ECBC also specifies light transmission values with respect to amount of glazing the building

Window Wall Ratio	Minimum VLT
0 - 0.3	0.27
0.31-0.4	0.20
0.41-0.5	0.16
0.51-0.6	0.13

Table 2.3-4 ECBC Prescriptive requirement for Daylight

IV. Shading

SHGC requirement can be affected by use of overhangs or side fins. It considers effect of projection in reducing SHGC for proposed design in prescriptive approach by multiplying SHGC of unshaded fenestration by multiplication factor M.

The projection factor calculation depending on the height and width of the shading is determined in accordance with sun azimuth, altitude, orientation of the building side.

Projection Factor = H (horizontal)/V (vertical)

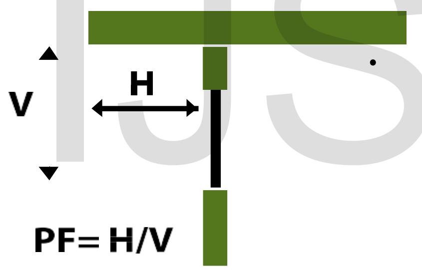


Figure 2.3-1 Projection factor (ECBC,2007)

Project Location	Orientation	Overhang "M" Factors for 4 Projection Factors				Vertical Fin "M" Factors for 4 Projection Factors				Overhang +Fin "M" Factors for 4 Projection Factors			
		0.25 - 0.49	0.50 - 0.74	0.75 - 0.99	1.00 +	0.25 - 0.49	0.50 - 0.74	0.75 - 0.99	1.00 +	0.25 - 0.49	0.50 - 0.74	0.75 - 0.99	1.00 +
North latitude 15° or greater	N	.88	.80	.76	.73	.74	.67	.58	.52	.64	.51	.39	.31
	E/W	.79	.65	.56	.50	.80	.72	.65	.60	.60	.39	.24	.16
	S	.79	.64	.52	.43	.79	.69	.60	.56	.60	.33	.10	.02
Less than 15° North latitude	N	.83	.74	.69	.66	.73	.65	.57	.50	.59	.44	.32	.23
	E/W	.80	.67	.59	.53	.80	.72	.63	.58	.61	.41	.26	.16
	S	.78	.62	.55	.50	.74	.65	.57	.50	.53	.30	.12	.04

Table 2.3-5 SHGC"M" Factor Adjustments for Overhangs and Fins

3. Impact of Solar Passive & Building Envelope Design

This chapter highlights basic passive design techniques considered and role of building envelope in warm & humid regions. It focuses on how building design can reduce solar heat and maintain required daylight and ventilation for the office space.

General passive cooling design recommended for tropical climate consists of 3 levels (IRJET, Vol 2, Issue 12, 2016)

Level 1- Site level building features- Location, Orientation, Land massing, Microclimate modification, Vegetation.

Level 2- Architectural Feature- S/V ratio, Screen, shade, overhangs

Level 3- Weather Skin Feature- Insulation, Glazing, Material type, Mass, Finishes

Below are physical manifestations in order to achieve comfort requirement in warm & humid regions

OBJECTIVES	PHYSICAL MANIFESTATION
Resist heat gain	
Decrease exposed surface area	Orientation and shape of building
Increase thermal resistance	Roof insulation and wall insulation
Increase buffer spaces	Balconies and verandahs
Increase shading	Walls, glass surfaces protected by overhangs, fins and trees
Increase surface reflectivity	Increase surface reflectivity
Promote heat loss	
Ventilation of appliances	Provide windows/ exhausts
Increase air exchange rate	Ventilated roof construction. Courtyards, wind towers and arrangement of openings
Decrease humidity levels	Dehumidifiers/ desiccant cooling

Table 3-1 Physical manifestation for passive cooling (Nayak & Prajapati ,2006)

3.1 SITE

The environmental conditions which influences the building design is largely based on the microclimate and macroclimate condition.

3.1.1 Landform

Landform represents topography of the site i.e mountain, valley, plains, coastal region are major landforms observed in Indian which dictates the wind and macroclimate condition.

The region in warm-humid area are normally flat with reasonable wind speed condition.

If there are slopes and depression, building should be located on windward side or crest to take advantage of cool breeze.

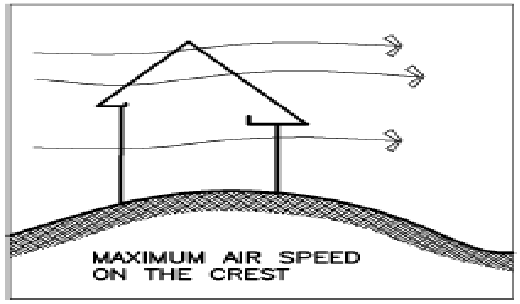


Figure 3.1-1 Building form at crest

3.1.2 Waterbodies

Presence of waterbody near the building absorbs the local heat from the surrounding. The wind flow is also influenced by presence of large waterbody as land heats up faster than water and causing the air over the land to rise which is replaced by cool air from water. Fountains ,ponds in the courtyard of the building further reduces the localised heat acting as heat sink and discharges cool , fresh air for natural ventilation for the building.

But since evaporation of water raises the humidity level, it is not an ideal factor in warm-humid climates. Eg- Mumbai, Chennai, coastal region.

3.1.3 Street Width

Street width & orientation is a vital factor for amount of direct radiation incident on building. Building near the vicinity can cast a shadow on the opposite building reducing sun's radiation.

In warm & humid climate, major streets should be oriented parallel to or within 30º of the prevailing wind direction during summer months to encourage ventilation. Mostly north-south direction is ideal from the point of view of blocking solar radiation and facing west wind ventilation.

3.1.4 Open Spaces

Courtyard which is a circumscribed area, surrounded by building components, complex and open to sky is a traditionally architecture passive approach majorly used in North India. These open spaces in India are called as "Brahmastana" the genius loci of the house (Bahl,2014).It creates an adaptive environment for daylight entrance and ventilation.

International Journal of Scientific & Engineering Research Volume 11, Issue 9, September-2020
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Figure 3.1-2 Courtyard space in Green Commercial Building-Suzlon, Pune

Large open spaces for unrestricted air movements. Building on stilts can promote ventilation and cause cooling at the ground level. Semi open spaces like Balconies, varandahs, porches are advantageous as temperature is not at very high and also it gives protection from rainfall. Humidity areas should be isolated.

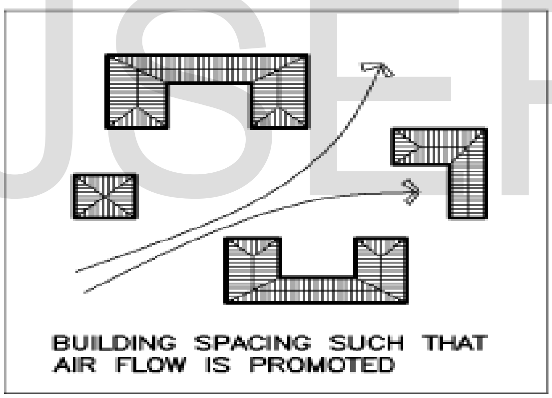

Figure 3.1-3 Building spaces in Warm & humid climate.

Figure 3.1-4 Building on Stilts (Mumbai)

3.2 Orientation & Compactness

The best orientation for the building requires maximum solar radiation in winter and minimum in summer.

Tropical region such as India ,mostly have excessive heat during summer months , thus if a designer orients the building in such a way that the longer axis of the building is along North-South so that longer walls face east west this brings down heat gain through walls in India . (P.P.Anilkumar, IJETAE ,2013)

The compactness of the building is measured using (surface area to volume)S/V ratio which is an important factor for heat transfer in and out of the building. Larger S/V ratio, greater is the heat gain. As for warm & humid region, ventilation is a prime concern which might not necessary reduce S/V ratio. An obstructed air path through interior is important. Long and narrow building could be preferred to promote cross-ventilation.

Since the temperature and diurnal temperature difference is less, free plans can be evolved with building being under shades. Cross ventilation can effectively reduce heat gain and humidity, thus long and narrow plans are encouraged (eg- rooms on single side of the corridor instead of double loading of the floor space)

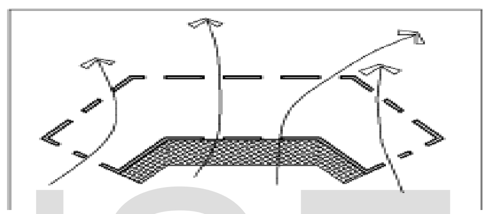

Figure 3.2-1 Elongated building form to increase ventilation

3.3 Building Envelope Components

The commercial and residential building have gone vertically up mostly in tier 1 & tier 2 cities which has increased the wall and window area ratio as compared to the roof area and thus heat gain through walls and window is far more significant as that compared to roof.. For the study- 4 cities with ground+4 height are taken that are in hot and dry zone, warm and humid zone.

Building component	Ahmadabad (223.037 MWh)		Mumbai (201.892 MWh)		Nagpur (198.756 MWh)		Pune (137.764 MWh)	
	Cooling load (MWh)	Percentage of annual cooling load	Cooling load (MWh)	Percentage of annual cooling load	Cooling load (MWh)	Percentage of annual cooling load	Cooling load (MWh)	Percentage of annual cooling load
Walls	81.141	36.4	66.532	33.0	71.151	35.8	36.487	26.5
Roof	18.996	8.5	15.148	7.5	17.845	9.0	12.288	8.9
Ground	4.957	2.2	4.557	2.3	3.000	1.5	-0.129	-0.1
Window	117.941	52.9	115.654	57.3	106.761	53.7	89.119	64.7

Table 3.3-1 Heat gain from various building envelope (Nayak,hazra,prajapati, 1999)

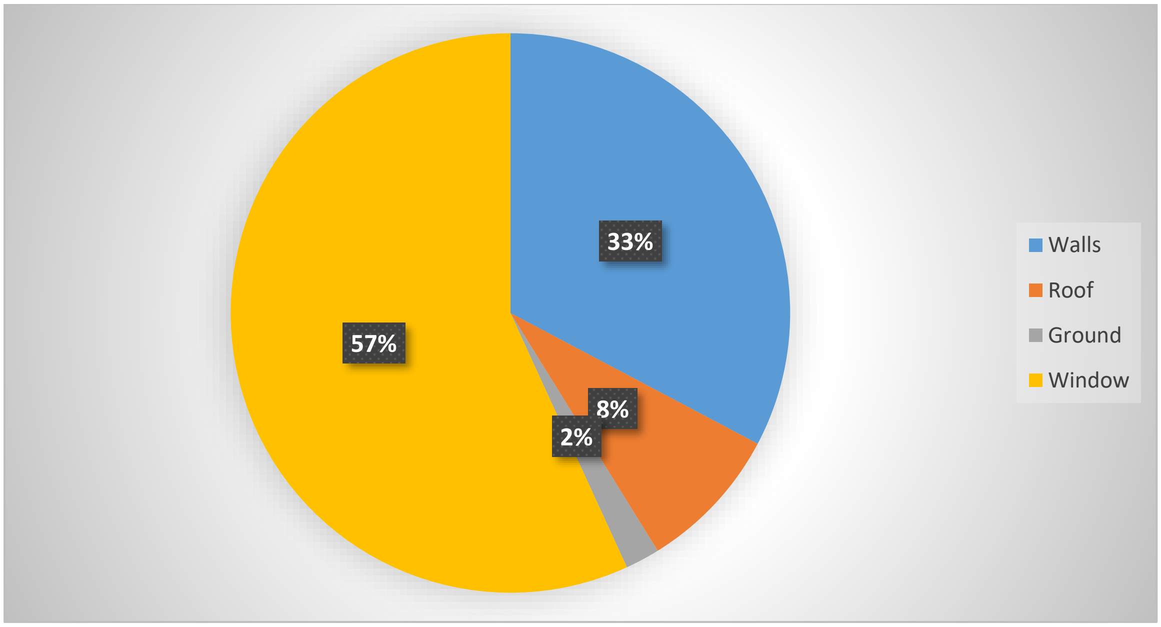

Figure 3.3-1 Average percentage of heat gain in 4 climate zones

3.3.1 Roof

As per Indian Standards I.S code- 3792-1978, the maximum U value for roof in hot –dry zone and warm- humid zone is set at 2.33 W/m^2K .

Predominantly RCC construction is the most common practice in India. Due to high thermal conductivity, additional layers are added to the construction to reduce the outside heat transfer in order to maintain standard ambient internal temperature.

The IS code and NBC also states some of the measures which can be used to reduce the heat gain in high and moderate temperature areas-

- Insulating the roof internally or externally considering waterproofing treatments if required.
  - Use of high performing insulation material with can be 100 times more effective than RCC in reducing outside heat. Eg- Expanded & Extruded polystyrene, Rock wool, Glass fibre insulation.
  - Conventional & traditional practice – Number of traditional cool roof material like mud phuska, inverted earthen pot technology, brick bat coba are widely used as economic cool roof solution to increase the heat resistivity for better internal temperature. The inverted pot of 175mm radius and depth 75mm creates an air gap between the RCC and outer layer, thus acting as an insulation layer.

Figure 3.3-2 Brick coba ovr RCC slab in Mumbai

Figure 3.3-3 Inverted Pot Cool Roof in Residential Building in Surat, India

- Flooding the roof with water by sprays or other means. Evaporative cooling of roof by removing latent heat from the roof surface through evaporation of liquid.
- White washing of roof (White paints) can be done before the start of summer (March). Reducing the heat through radiation.

International Journal of Scientific & Engineering Research Volume 11, Issue 9, September-2020
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Figure 3.3-4 White washing in south India

Below is the result of the study in Reference Manual DOE, Los almos National Laboratory-which has considered above techniques for flat roof in hot and dry climate on 2 consecutive summer days and found that average internal ceiling temperature was reduced by about 10°C. The results highlight that for peak temperature 45°C, white washing reduces the temperature by 15°C insulation and spraying of water and insulating the roof showed about similar results of internal temperature of around 25°C.

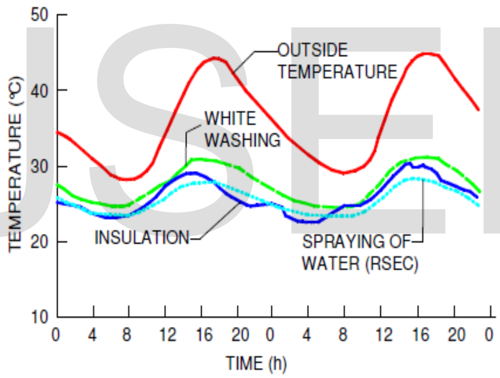


Figure 3.3-5 Relative performance of different techniques on a flat roof (IS-3792)

3.3.2 Walls

As per Indian Standards I.S code- 3792-1978, the maximum U value for wall in hot –dry zone is 2.56 W/m^{2}K and for warm- humid zone is 2.33 W/m^{2}K.

Along with U value, code also states below thermal properties and prescribed maximum and minimum value

- Thermal performance INDEX (TPI) – It refers to calculation of allowable internal peak temperature in reference to the outside peak temperature.
  For non-air conditioned building
  TPI= ($T_{internal}$-30) *100 / 8
  where 30°C is considered as comfortable temperature for non-air conditioned building as per Indian standard and maximum rise of 8°C which causes discomfort.
  For air conditioned building, as per ASHRAE, 1981

TPI= (q-46)*2.5 (q-peak heat gain factor)

Thus with heat gain reference of 46 W/m^2, peak heat gain factor for the wall is calculated.

TPI		**Class**	**Quality of performance**
Non A/C building	A/C building		
≤ 75	≤ 50	A	Good
≥ 75 ≤ 125	≥ 50 ≤ 100	B	Fair
≥ 125 ≤ 175	≥ 100 ≤ 150	C	Poor
≥ 175 ≤ 225	≥ 150 ≤ 200	D	Very poor
≥ 225	≥ 200	E	Extremely poor

Table 3.3-2 Thermal Performance Index Rating & Classification

- Thermal Damping – It is the ratio of difference of diurnal outside and inside set temperature to outside temperature. This helps to give the effect of the wall on reduction of temperature. The minimum thermal damping for exterior wall is 60 %. This is not an ideal wall property in warm & humid climate, as the diurnal temperature variation is much less, it is useful in composite climate where extreme dry climate as well as cold harsh climates are observed.

- Thermal time constant – It is the ratio of total heat gain by the wall to thermal conductance which refers to the time required for the wall to be entirely heated. The minimum time as per standard is 16 hrs for exposed walls.

Below are the some prescribed ways to achieve a thermal resistive walls as per Indian standards

- Increasing thickness of the wall which increase the thermal mass as thermal resistance is directly proportional to thickness.(R= d/ λ)
- Cavity wall construction
- Use of insulation in the wall, provided it meets structural requirement.
- Light coloured white wash or distemper may be applied on exposed walls.

3.3.3 Windows & Fenestration (Glass)

Glass has the most significant impact on the energy consumption of the building. The tropical Indian climate demands a reduced heat transfer from outside to inside, so as to reduce the internal surface temperature which in turn reduces the cooling loads, especially in summer season.

The infrared spectrum including short and long wavelength is key in heat transfer process through radiation along with conduction and convection. A high performance glass which reduces infrared penetration, while allowing passage of light in visible wavelength will help in decreasing the overall energy consumption of the building.

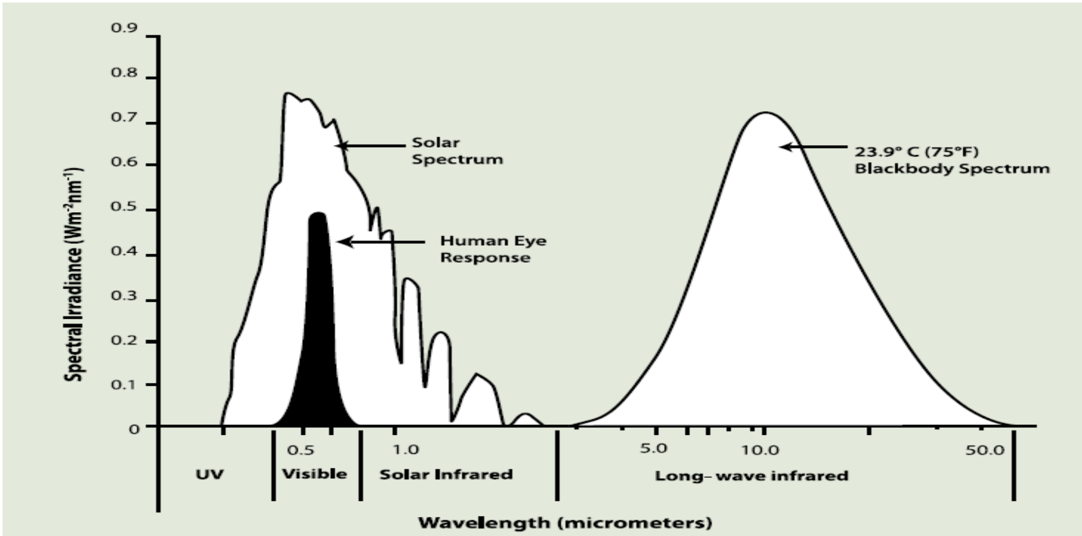


Figure 3.3-6 Solar spectrum (Wavelength)

Selection of glass also depends on the overall WWR and the daylight requirement factors. Recommended daylight factor for office space as per Indian standards is 150 lux. Thus in order to achieve the same, below VLT and WWR relationship recommended-

*1 Daylight factor (DF)= 80 lux

Daylight Factors at the Centre of the day lit zone										
Visual Light Transmittance of Glass (%)	DF for WWR 10%	DF for WWR 20%	DF for WWR 30%	DF for WWR 40%	DF for WWR 50%	DF for WWR 60%	DF for WWR 70%	DF for WWR 80%	DF for WWR 90%	DF for WWR 100%
10	0.3	0.5	0.6	0.7	0.8	0.8	0.9	0.9	0.9	0.9
20	0.6	1.0	1.2	1.4	1.5	1.7	1.7	1.8	1.8	1.9
30	1.0	1.6	1.8	2.1	2.3	2.5	2.6	2.7	2.7	2.8
40	1.2	2.1	2.4	2.8	3.1	3.3	3.4	3.6	3.6	3.7
50	1.5	2.6	3.1	3.5	3.8	4.1	4.3	4.5	4.5	4.6
60	1.9	3.1	3.7	4.2	4.5	5.0	5.2	5.4	5.4	5.6

Figure 3.3-7 Daylight factor for WWR and VLT Relation (Indian standard S&P-41)

4. Evolution in Energy Efficient Measures

In Pre- ECBC era, energy efficient buildings in India concentrated on solar passive design strategies and building envelope were designed considering Indian standards and NBC -2005. i.e- proper orientation, minimum WWR, natural ventilation, daylight, shading etc to reduce energy consumption and to meet thermal/light comfort as per Indian standards.

Post modernisation in building envelope in mid-2000, efficient buildings are considering energy saving measures in building envelope, active HVAC and censors. As per study by TERI and White box technologies, USA, which considered study of around 13 buildings in different climatic regions.

Below is comparative analysis of the study-

Parameters	**Conventional Building (Worst- case)**	**Low energy buildings (Solar passive)**	**ECBC Compliant Building**
Orientation	Longer axis faces East-west	Longer axis faces North- South	No Specification- (as per existing building)
Shading	No shading	Wall and roof shading	No shading specification (as per existing building)
Glazing	Single glazed Window U value-6.17 W/m^{2}K	Mix of single and double glazed window	Double glazed windows U value as per ECBC- 2007
Wall construction	250mm brick wall+ 12.7mm plaster on both sides U value-1.98 W/m^{2}K	Same as Conventional Building. (The maximum U value 2.91 Warm-humid zone) – IS 3792	250mm brick wall+ 12.7mm plaster on both sides+ Exterior Insulation U value as per ECBC- 2007
Roof Construction	250mm RCC + 250mm Brick Coba +25.4 mm clay tile U value-1.76 W/m2K	Same as Conventional Building (The maximum U value- 2.33 W/m^{2}K) – IS 3792	250mm RCC + 250mm Brick Coba +Exterior Insulation+ 25.4 mm clay tile U value as per ECBC- 2007

WWR & Min. VLT	Not specified	As per BIS (SP:41 S&T) Ranges from 10- 100% 10% WWR-0.60 20-30% WWR- 0.40 40-70% WWR-0.30	U value as per ECBC- 2007 Recommended 40-60% WWR
Natural Ventilation	No natural ventilation, Conditioned area is above 60%	Circulation areas are natural ventilated Conditioned area is above 50-65%	Circulation areas are not natural ventilated Conditioned area is above 60%.
Light performance Density	21 W/m^2	15-20 W/m^2	10.8 W/m^2

Table 4-1 Conventional v/s Solar passive v/s ECBC Design

Thus, ECBC design focuses majorly in optimizing energy through use of effective building envelope and efficient HVAC & lightning system promoting use of double glass unit and solar coatings to reduce heat through windows & insulation in wall & roof, further decreasing heat transfer value.

Below are some of the studies highlighting energy savings through building envelope

Project Detail	Conventional Case	ECBC Envelope	Energy reduction (Envelope)
WIPRO Info tech Banglore (Moderate climate zone)	1. No roof and wall insulation Roof (U-1.94 W/m^2K) Wall (1.5 W/m^2K) 2.Windows- SGU (U-6.17 W/m^2K) , SC-0.61) WWR-26% 3. Windows , wall not shaded 4. Long facades facing east-west	1. Roof Insulation & air-gap for walls Roof (U-0.47 W/m^2K) Wall (U-1.29 W/m^2K) 2. DGU (U-2.64 W/m^2K) , SC-0.17) WWR-26% 3. Windows shaded E-W Orientation 4. Long facades on N-S and short on E-W	1. Cooling reduction (TR)- 13.6% from conventional case 2. EPI(kwh/sqm/yr)- 12.6 % from conventional case

Microsoft India development center, Hyderabad (Hot & dry zone)	1. No roof and wall insulation Roof (U-1.76 W/m^{2}K) Wall (1.98 W/m^{2}K) 2. Windows - SGU (U-6.17 W/m^{2}K, SC-0.61) WWR-70% 3. Windows , wall not shaded 4. Long facades facing east-west	1. Roof Insulation & air-gap for walls Roof (U-0.232 W/m^{2}K) Wall (U-1.85 W/m^{2}K) 2. DGU (U-1.66 W/m^{2}K) , SC-0.0.28) WWR-70% 3. Windows & roof shaded 4. Long facades facing east-west	1. Cooling reduction (TR)- 24% from conventional case 2. EPI(kwh/sqm/yr)- 15.35 % from conventional case
WIPRO, Kolkata (Warm-Humid zone)	1. No roof and wall insulation Roof (U-2.74 W/m^{2}K) Wall (1.92 W/m^{2}K) 2.Windows- SGU (U-5.7 W/m^{2}K , SC -0.52) WWR-11% 3 No shading for roof, wall, windows) 4. Longer facades of the building are 45° inclined to north.	1 . Wall as per ECBC recommendation (24-hours) Roof (U-0.261 W/m^{2}K) Wall (0.44 W/m^{2}K) 2.Windows- DGU (U-3.3 W/m^{2}K , SC -0.287) WWR-11% 3. E-W façade and wall shading 4. Longer facades of the building are facing north–south.	1. Cooling reduction (TR)- 13% from conventional case 2. EPI(kwh/sqm/yr)- 5 % from conventional case

Table 4-2 ECBC Case Study Results (TERI & White box technology)

Figure 4-1 Microsoft India, Hyderabad (ECBC recognised building)

Figure 4- 2 Wipro, Kolkata (ECBC envelope & courtyard design)

5. METHODOLOGY

The basic approach to achieve the objective of the study involves collection of the data with respect to the building and simulating it on **eQuest** software for further analysis. Source like ASHRAE, Indian Standards, NBC, ECBC have been used in the study.

The methodology is basically divided into below 4 steps-

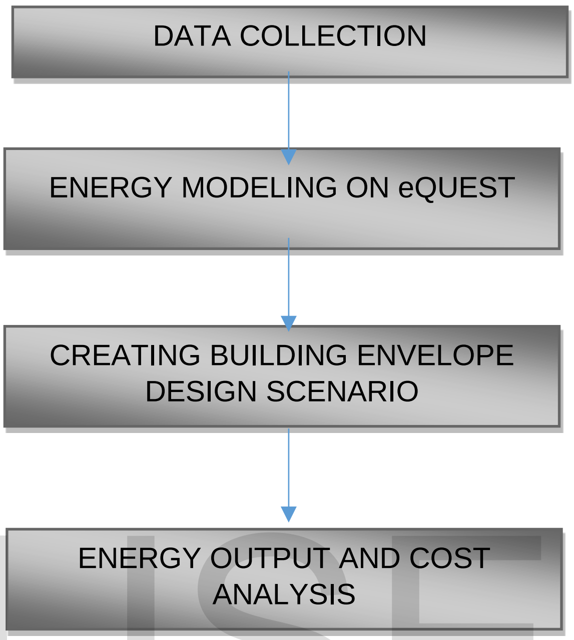


Figure 5-1 Research Methodology

5.1 Data collection-

The first step of the project is to collect below data which were basic requirements of the project.

1. Architectural/ Civil data
   - Specification of windows
   - Elevation (all 4 sides)
   - Each floor plan (Ground +7)
   - Sectional view
   - Wall configuration
   - Roof configuration
   - Internal architecture

2. Maintenance data
   - Lighting specification
   - Chiller parameters
   - Air handling unit specification
   - HVAC System
   - Thermal zoning areas- (Conditioned/un conditioned)

3. Costing Data

   In order to calculate payback period, the cost considered is only for basic material involved in the scenario (excluding labour, taxes, and any other structural or additional cost). The cost/ sq.mt calculation are derived considering below reference

- ➢ Roof and Wall Material cost– CPWD, Analysis of Rates (Vol 1 & 2)
- ➢ Insulation, Glass and other material cost- System/Component provider & Façade contractor.
- ➢ Energy cost per kWh is drawn from MSEB (Maharashtra State Electricity board)

Since the extracted rated were in Indian currency units, it is converted to USD. **70 (Indian National Rupee) = 1 USD** (Foreign Exchange Association)

5.1.1 Basic Climatic Design Data

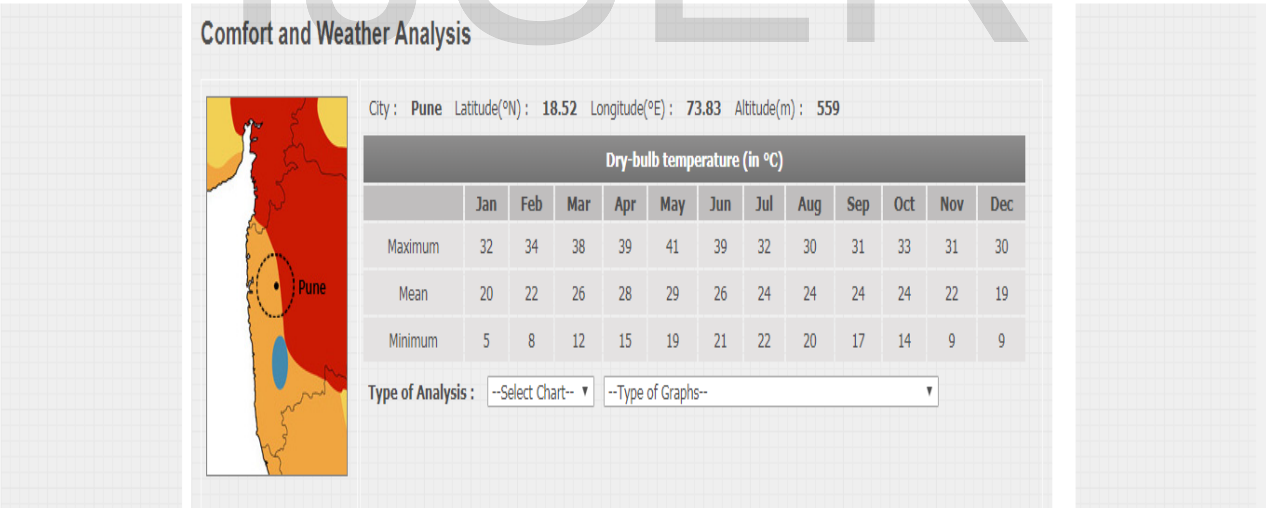
Project Location- Pune (18.52°N, 73.83°E)

Climate zone- Warm & Humid

Maximum & minimum temperature – 41°C in May & 5°C in January respectively

Maximum Precipitation- 211mm in July (Monsoon period)

Average Relative Humidity – 60%



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Maximum	32	34	38	39	41	39	32	30	31	33	31	30
Mean	20	22	26	28	29	26	24	24	24	24	22	19
Minimum	5	8	12	15	19	21	22	20	17	14	9	9

Figure 5.1-1 Pune Temperature Data (CEPT University)

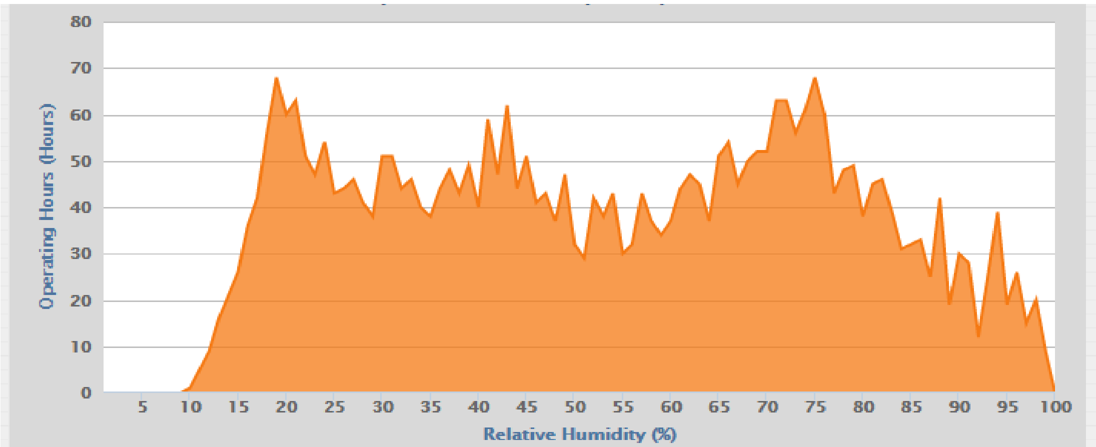


Figure 5.1-2 Humidity Distribution for Daytime Space building-Pune

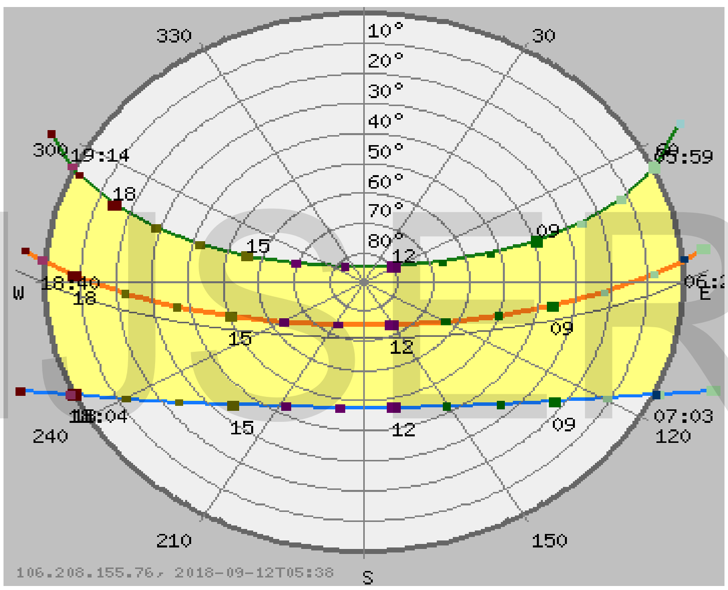


Figure 5.1-3 Sun path diagram-Pune

5.1.2 Building Data

Storey size- Ground +7

Schedule workig hours- Monday to Friday (9am -6pm)

Orientation- North-South (Longer axis)

The building is almost rectangular in shape but has a curved shape on west side which is the enterance side of the building. The east side where openable windows of 1.5m x 1.5m are placed for ventilation & daylight in office spaces. Due to highly glazed west side, balanced with thermally protective south side ,the overall WWR is 52%. The curtain wall with structural box of depth 140mm & width 55mm placed at regular intervals of 1.5 m has 4mm aluminium composite spandrel panel. The enterance of the building is spider glazed upto 5 storey height. Only the workspace is fully air conditioned, while the areas like corridor, atrium , washroom, ground floor are unconditioned areas. With varying floor plan area due to the geometry of the building, typical floor area ranges between 2220 sq.m to 2300 sq.m where around 70-75% of floor area is workspace.

	Workspace
	Washroom/Toilet
	AHU – 3 nos
	Elevator lobby/stairs
	Electrical room
	Atrium space
	Corridor

Figure 5.1-4 Typical Floor plan

Figure 5.1-5 West Side Elevation

Figure 5.1-6 West & North side elevation

The HVAC system type used in the building is constant air-volume type. The building is cooled by 2 screw chillers, each with 375 TR. There are total 21 AHU's in the building- 3 per floor where 14 AHU discharges 21500 cfm and the rest 7 discharges 14500cfm.

The lighting layout is found to be based on recommended illumination level as per National Building code. Corridors and general circulation spaces were designed at 70 lux, staircase for 100 lux, parking areas at 30 lux, lift lobbies at 150 lux and office and meeting rooms at 300lux.

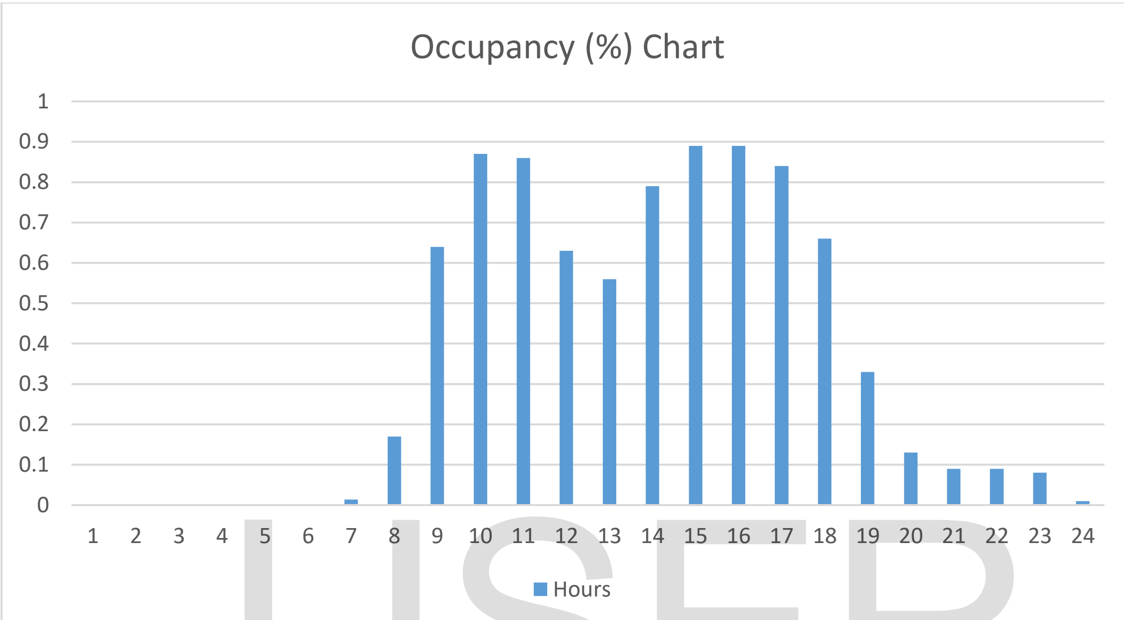


Figure 5.1-7 Occupancy Chart

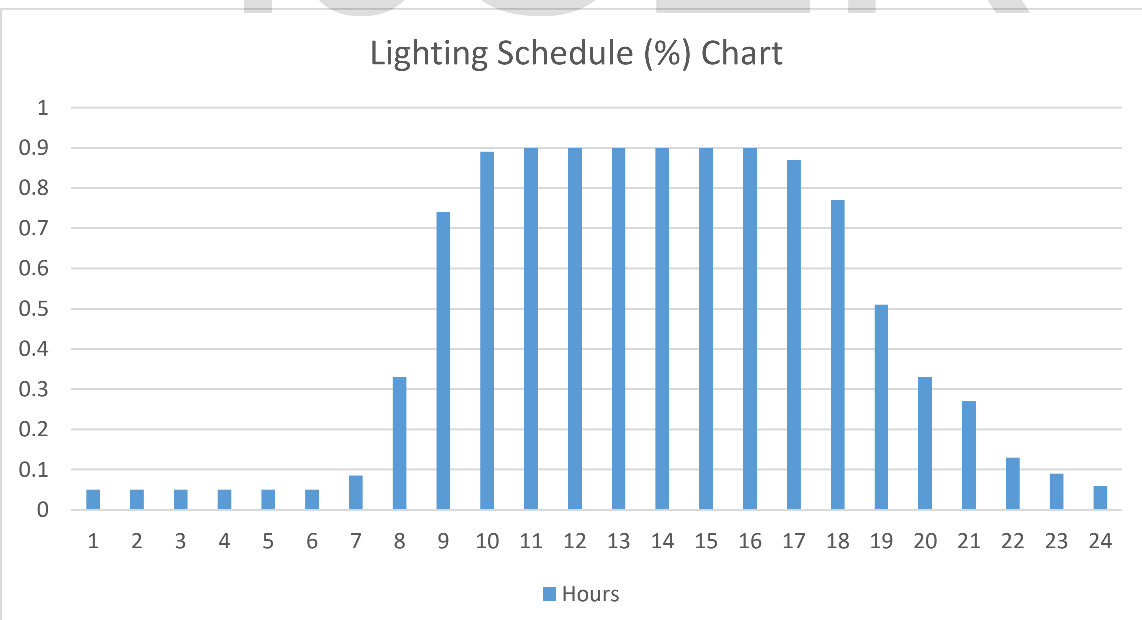


Figure 5.1-8 Lighting Schedule Chart

5.2 *E-Quest Software*

Various software packages are available today such as Energy Plus, ESP-r, IDA ICE, TRNSYS, e-Quest, Trace700, etc, for energy analysis (Sousa, 2012). In this study, energy modelling has been done using e-QUEST energy analysis software that runs on DOE 2.2 building energy simulation engine. eQUEST is supported as a part of the Energy Design Resources program which is funded by California utility customers and administered by Pacific Gas and Electric Company, San Diego Gas & Electric, and Southern California Edison, under the auspices of the California Public Utilities Commission. The version in which the model run is the latest available for eQuest – Version 3-65 released on 2016.

The creation of an energy model goes through a number of iterations and multiple simulations are run to ensure that it is accurate and calibrated. The three main categories of variable are-

- Weather & Climate
- Energy and utility
- Building components

The weather data available on e- Quest is based on American & Canadian regions with reference to temperature of a particular location as well as its solar orientation. The user can change the climatic condition depending on the project location by feeding .bin weather file in project & site data tab.

The design simulation for the year contains 8,760 hours, HVAC load can be calculated from standard data sets.
Building components being the broadest category during the modelling of the project. It is divided into various sub categories – Envelope construction, Spaces & Usage, HVAC system detailing. This along with geometry definition forms the 3D-base on which the simulation will be run upon.
Thus the basic inputs required for the study includes-

- Building site data (i.e Orientation, Weather)
- Building envelope data (i.e Walls, Roof, Glass, Shades, Internal construction detail)
- Building operation & scheduling (i.e Occupancy. HVAC shedules)
- Internal loads (i.e- body heat, lights, equipment)
- HVAC equipment and performance
- Utility and economic parameters (if required)

Thus the results obtained are-

- Summary of projected annual utility consumption and savings
- Performance graph (Electricity and gas consumption detail, monthly wise data)
- Input parameter information (e.g., internal load specifications, building envelope Characteristics, HVAC system definitions, etc.)
- Assumptions of building characteristics
- Interpretation of results
- Software input and output files (electronic)

5.3 MODELLING PROCESS

The existing building project data is used for the initial modelling for analysing hourly energy simulation to explore modified measures for energy savings through building envelope.

Below is a flow chart highlighting sequence of operations

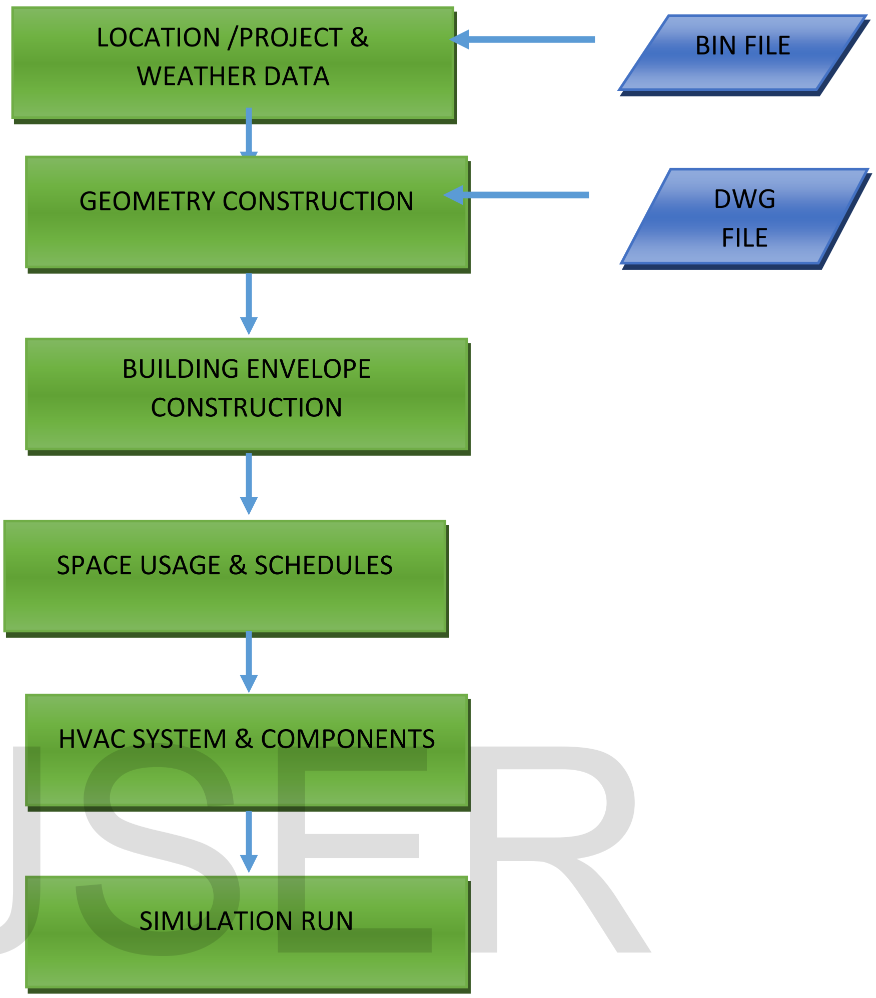


Figure 5.3-1 Modelling Process Flow chart

1) The modelling process is carried on Design Development Wizard where multiple shell components can be created. There were basically 5 different plans with changing areas with a constant storey height of 3.65 m
   - Ground Floor Plan
   - First & Second Floor Plan
   - Third & Fourth Floor plan
   - Fifth Floor Plan
   - Sixth & Seventh Floor Plan

   Further the thermal zones for the building were customised as only the office space is air-conditioned, while lobby, corridors, ground floor, mechanical/electrical room are non-air-conditioned.
   Total Conditioned area- 74%

2) The weather file obtained from ISHRAE is in .epw file which is converted to .bin file through DOE converter, containing hourly values of dry and wet bulb temperature, wind speed, solar altitude & azimuth, direct and diffuse solar radiation, humidity & moisture content.

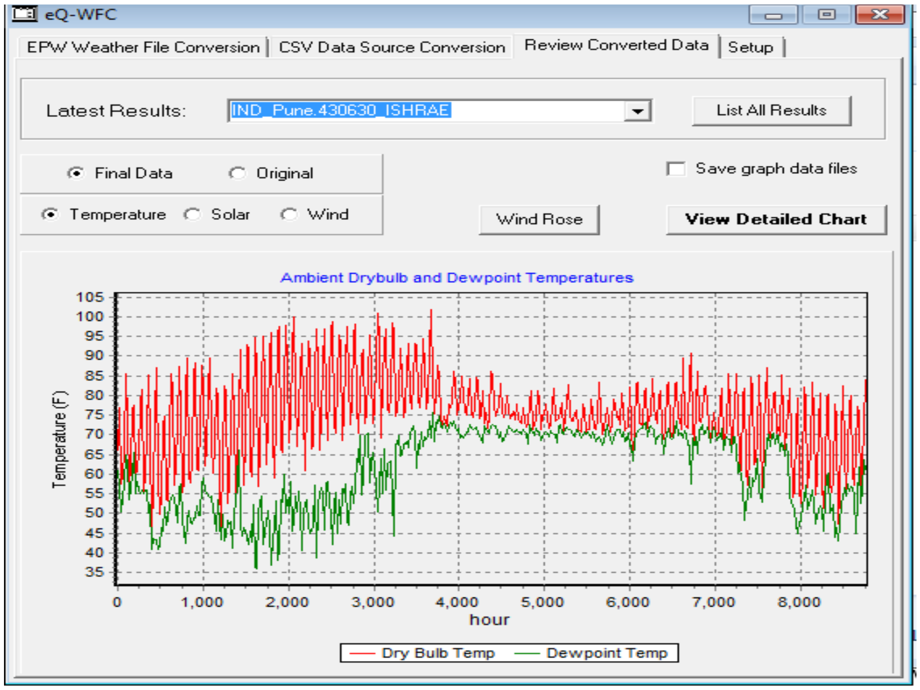


Figure 5.3- 2 Converted .bin data

3) Next, 5 different building shell components are created and the geometry for each shell component is imported from CADD (.dwg file) to e-Quest, where the plan is traced and building orientation and floor height data are inserted.

4) Existing Building envelope construction data is initially entered and then modified specification data, depending on different scenarios which are processed.

   The screen includes-

   Roof construction, above grade walls, Ground floor, Ceiling, Slab construction, Exterior doors, Exterior Windows and Glazing

   Apart from roof and exterior wall and glazing construction, all the other construction parameters are kept constant.

   The floor construction is 160mm RCC with carpet finish, all the internal vertical walls are with masonry construction. The storey height of 3.65 m has 0.6m ceiling height with internal acoustic ceiling finish.

   The window and curtain wall placements are customized for the each storey. The curtain wall for top half of the building is storey height glazing while at the bottom with spandrel panel, the glazing height is 2m.

   The windows placed at the east are of 1.5 x1.5 m

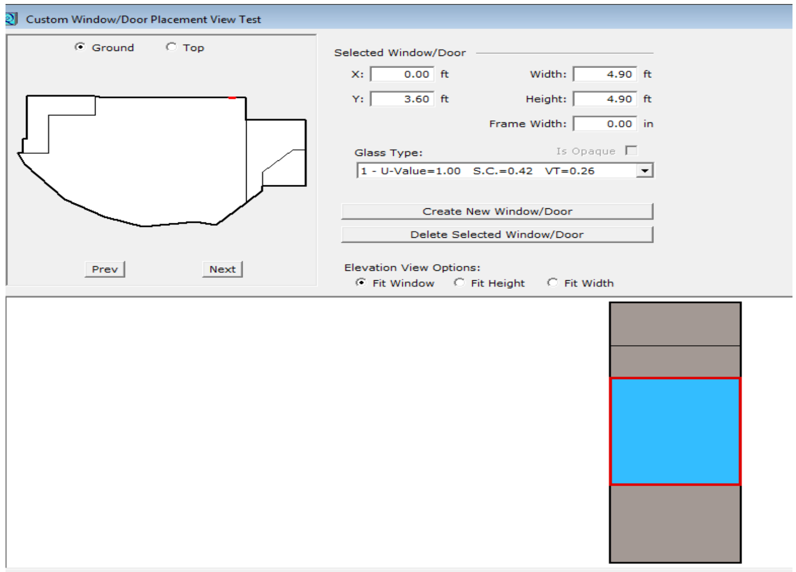


Figure 5.3-3 Customised Windows Screen

5) The scheduling hours were set from 9am to 6pm and the design maximum occupancy and ventilation rate were set as default as per ASHRAE standard 62

Area Type	Max. Design Occupancy (sq.m/person)	Design ventilation (cfm/person)
Office	9.3	15
Atrium	2.3	7.6
Corridor	9.3	15
Lobby	9.3	15
Restroom	9.3	15
Conference room	1.4	7.5
Mechanical /electrical room	31	50

Table 5.3-1 Design occupancy & ventilation

6) HVAC system were defined for each floor with water coil used as cooling source, while no heating source were defined. The cooling internal set point temperature defined during working time is 24°C as defined in ASHRAE 90.1. The chiller considered are 2 screw chiller (375 ton each) with COP 4.5

7) Further in order to simulate with real background condition, fixed shading provided by the near mall – 30m away from the south side wall is designed.

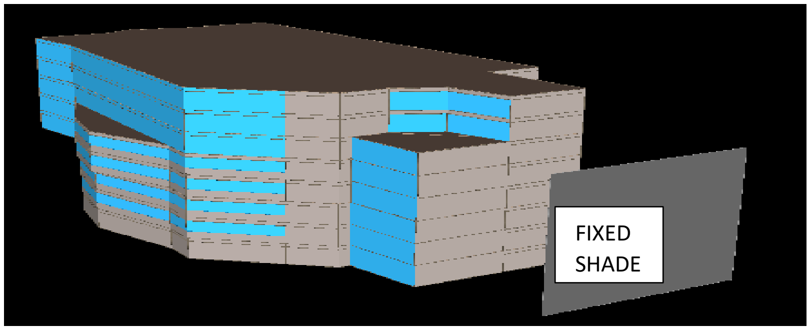


Figure 5.3-4 Fixed Mall shading

8) The internal lighting consumption is calculated considering fluorescent lights with luminous efficacy (lumens /watt) of 60. The daylighting mode is switched on and the lighting point is set at 538 lux and the direct on/off switch is used, thus operating when the illuminance levels due to daylight fell below 538 lux.

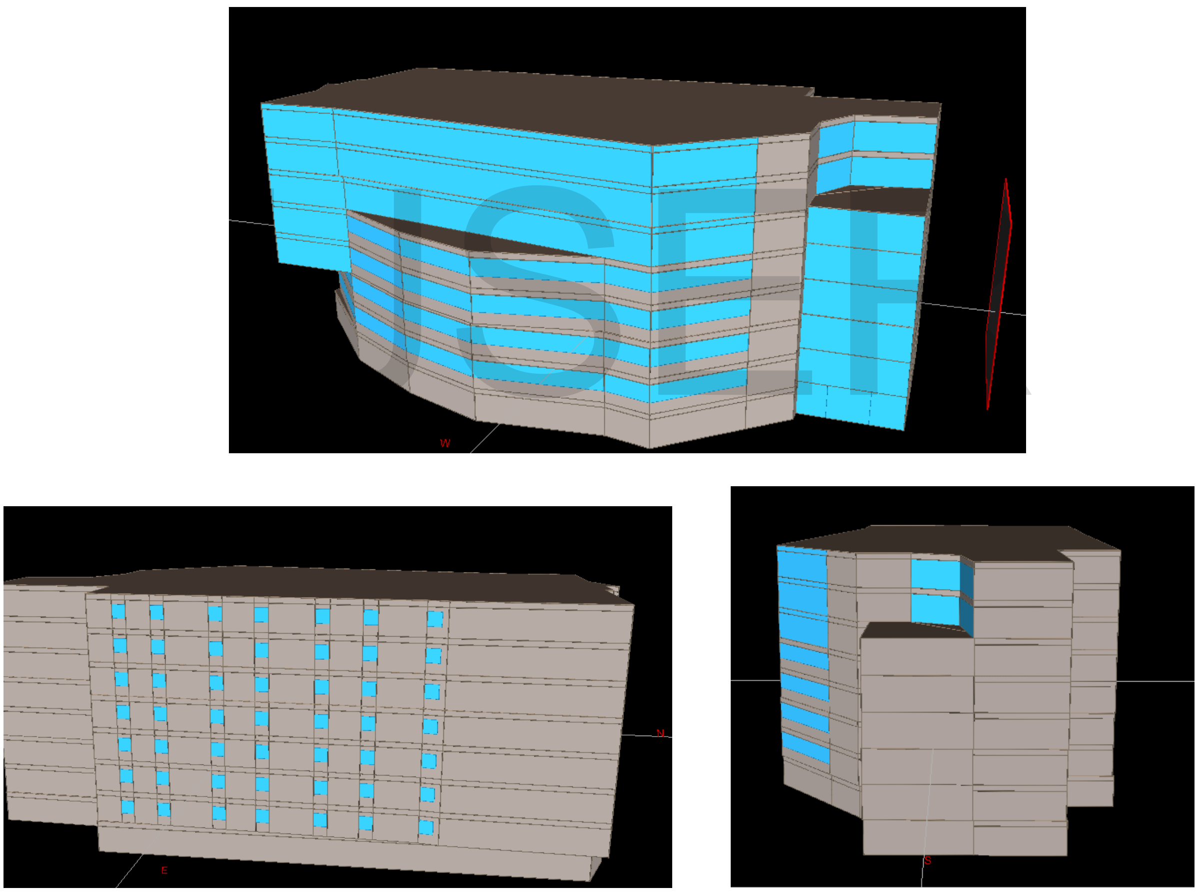


Figure 5.3-5 Building 3D view on Equest

Top- West side elevation

Bottom left- East side elevation

Bottom right- South side elevation

6. Design Scenarios

The building envelope scenarios are modified in order to analyse the impact on energy consumption of the building, keeping the HVAC , lighting and other energy consuming elements the same.

6.1 Envelope Component Consideration

Below are the envelope components and analysed specification which were modified in different scenario cases to increase the performance of the building and reduce the energy consumption.

Components	***Analysed Specifications***
Wall	R value U value
Roof	R value U value
Glass	Shading coefficient (SC) U value VLT

Table 6.1-1 Analysed specification for Envelope Components

- Wall & Roof
  The thermal resistivity R value highlights the thermal resistance for heat transfer through the envelope. The resistance dependent on the thickness and thermal conductivity underlines the thermal performance of the layer and the integration of these layer results in determing the thermal performance of wall & roof. The
  The thermal conductivity (U) is inversely proportional to resistivity, thus a lower value of conductivity marks a higher thermal resistance and thus reduce heat flow (from outside to inside)
  The Internal and external surface resistance is considered for worst case static condition with values as per (BS EN ISO 6946)
  Wall- 0.13 m^2-k/w and 0.04 m^2-k/w respectively.
  Roof – 0.10 m^2-k/w and 0.04 m^2-k/w respectively.

- Glass
  Glass is used in below façade
  - Openable Window
  - Curtain wall
  - Spider Glazing on Entrance

  The glass specifications are taken from **Saint Gobain glass manual**

The glass selected in the design are modified for better U value, Shading Coefficient (SC) value, VLT in different scenario to the study the effect on energy consumption.

- SC – The shading coefficient links with the radiation heat transfer in the glazing unit. A lower value SC glass reflects the direct solar heat and thus absorbing reduce solar radiation, which reduces the heat transfer in glass.

Lower SC glass are observed to be more dark tint as compared to higher SC glass.

- VLT- The coefficient impacts the artificial lighting consumption. Thus a higher VLT coefficient glass enhance the daylight condition, reducing the loads on artificial lighting, especially for daytime building.

Since it is seen that cooling and lighting energy constitutes major portion of energy consumption in tropical climate buildings, a high performance glass having lower SC and higher VLT will help in reducing both cooling & lighting loads.

6.2. Different Case Scenarios

On examining the existing building configuration for walls, roof , glass, a total 5 different envelope cases are considered for reducing the final energy consumption.

Case 1- Indicates the existing case scenario

Case 2- Indicates recommendation from Indian standards for maximum prescribed U value for Wall & Roof

Case 3- Modified Case scenario

Case 4- Modified case scnario

Case 5- Specifications are based on recommendation from ECBC Prescriptive requirements

The thermal properties for wall & roof specification are drawn from National Building Code (SP 7:2005)

All the R value and U value calculation for roof and exterior wall are in Appendix A

6.2.1 Roof Scenario

Case 1

The existing roof is 160mm Renforced Cement Concrete (Density- 2288 kg/m^3) with 4mm thick outer PVC membrane as waterproofing layer.

Case 2

In this scenario, the roof specifcation are considered as per maximum prescribed U value in Indian Standard (S & P- 41,1987)

In order to reduce U value from 4.17 to below 2.33 W/m^{2}K, an additional layer of lime concrete is considered along with same 4mm thick PVC waterproof finished with tile. Thus in this case reduce heat transfer can be observed as additional thermal mass layer will absorb the heat.

(Inside)- 200mm RCC- 100mm lime concrete – 25mm tile (Outside)

Although the above configuration decrease the heat transfer , it increases the dead load of the roof by 75% from case 1.

Case 3

The roof specification is modified considering both thermal and water tightness parameter.

As per study by US department of Energy and BEE, India along with TERI & White box Technology, USA on- High Performance Building, one of the common roofing configuration for effective thermal comfort and reducing water leakage from roof is-

(Inside) 250mm RCC slab with -110 mm Brick bat coba – 25mm tile finish (outside)

The brick bat coba being one of the traditional economic way of waterproofing flat roof where the burnt bricks are placed to give a slope and then grouting it with cement mortar admixed with water proofing compounds. These bricks are soaked in water for atleast for 12 hours prior installation.(CPWD, Govt of India). Thus adding another thermal mass layer over the RCC roof and finishing off with tile.

The disadvantage is that it increases the dead load of the roof and if wide temperature variation is observed which is unlikely in warm-humid regions , the brick can crack and encourage water leakage.

Case 4

Overdeck insulation with appropriate PVC waterproof layer is being considered over existing case of 160mm RCC finished with tile. The insulation layer reflects the outside heat and reduces conduction heat transfer.

RCC (160MM) – XPS Insulation (60mm) – 4mm PVC waterproof layer- 25mm Tile

Thus considering Extruded polysterene insulation having very low thermal conductivity and low moisture resistance along with waterproofing layer for water resistance acts as an addition layer for thermal comfort.

Case 5

The roof configuration selected is considered through an ECBC Pilot study Project which was modified in hot- dry region (MNIT, Jaipur). The U value prescribed by ECBC is maximum **0.409** ***W/m²K.***

A double insulation layer-XPS Insulation and an economic traditional inverted earthern pot layer for reduce heat transfer is considered. A waterproofing membrane between insulation and inverted pot is placed for reducing water migration.

The burnt inverted pot (diameter-175mm, depth-75mm) cool roof technology placed over insulation further increases the system R value by traping the hot air between the roof and final surface.

(Inside) 160mm RCC slab-60mm XPS Insulation-4mm PVC waterproof layer-75mm inverted pot-20mm cement mortar

SUMMARY-

Roof case scenario	**R value (m^2K/W)**	**U value (W/m^2K)**
1-Existing	0.24	4.17
2	0.44	2.3
3	0.5	2
4	2.34	0.43
5-ECBC	2.63	0.38

Table 6.2-1 Alternative Roof Scenario Specification

6.2.2 Wall Scenario

Case 1

The existing exterior wall is of 200mm burnt brick masony wall (density -1820 kg/m^3) with 15mm cement plaster outside and 15 mm gypsum plaster inside.

Case 2

The exterior wall can remain the same as the existing wall construction is well below maximum prescribed U value of 2.91 W/m^{2}K (S& P- 41)

As per Indian standards , in warm- humid climates ,200- 230 mm masonry brick wall is a common specification in most of the municipal construction bylaws.

Case 3

In this scenario, to further reduce the R value of the system , cavity wall construction is considered with cement plaster at the exterior end and gypsum plaster at interior. This increases the thermal resistance due to dual thermal mass material, thus reducing heat transfer.

The exterior wall acting as façade to the interior thermall mass wall protecting from exterior rain and moisture penetration.

Configuration-

(Inside) 15 mm cement plaster – 200 mm Brick wall – 20mm cavity- 115 mm Brick wall- 15 mm gypsum plaster (Outside)

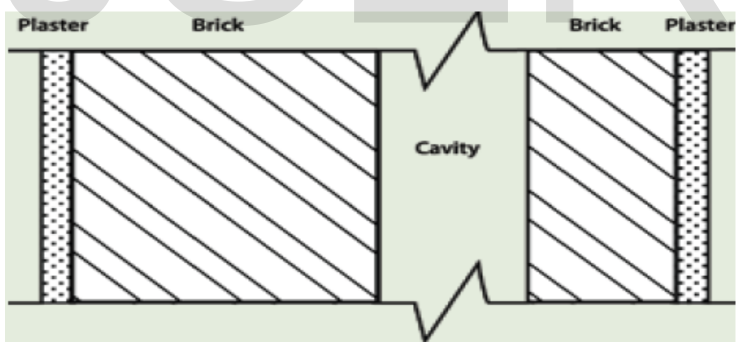


Figure 6.2-1 Cavity Wall Construction

Case 4

The wall construction considered is 200mm brick wall with gypsum plaster inside and EIFS (Exterior insulation finish system) on outside.

Configuration-

(Outside) 15mm plaster- 60mm XPS insulation- 200mm brick wall- 15mm gypsum plaster.(Inside)

An exterior water membrane over the insulation will reduce the probability of masonry wall in contact with water penetration.

Exterior insulation is considered as insulating from inside will reduce the office space by around 7%.

Case 5

Cavity wall in Scenario 3 is modified by placing insulation in the cavity , which reduces the conduction & convection heat transfer. The U value prescribed by ECBC is maximum **0.44** ***W/m²K.***

(Inside) 15 mm cement plaster – 150 mm Brick wall – 50mm XPS cavity insulation – 100 mm Brick wall- 15 mm gypsum plaster (Outside)

SUMMARY-

Wall case scenario	R value (m^2K/W)	U value (W/m^2K)
1-Existing	0.47	2.12
2	0.47	2.12
3	0.79	1.27
4	2.54	0.40
5-ECBC	2.24	0.44

Table 6.2-2 Alternative External Wall Scenario Specification

6.2.3 Glazing Scenario

The glass selection being the most complicated part in designing case sceario to balance out cooling and lighting load.

Thus glass specification scenarios were selected based on different façade and window combinations. All the glass selection are heat strengthened toughened glass.

- Windows- East and north side
- Curtain Wall- West Side
- Spider Glazing – West Side Entrance

Further different glass property combinations (U value, SC, VLT) were considered for reducing the final energy consumption.

Case 1

The glass currently installed at the project site is-

- Windows & Curtain Wall

Saint Gobain Toughened SGG Reflactasol Green-6mm -Green Tinted Glass with solar coating on face 2. A low VLT specification with moderate SC and high U value single glass unit**.**

- Spider Glazing

Thermally toughned 12mm Planilux single clear glass with very high VLT coeffecient and high SC & U value.

Case 2

The glass in this case gave more priority to daylight , thus a higher VLT specification in DGU is selected. This resulted in increase in SC value.

- Windows & Curtain Wall
  Saint Gobain Planitherm (6mm-12mm air gap-6mm clear glass)
- Spider Glazing
  Same as Scenario 1 as VLT specification is high.

Case 3

The glass selected in this case gave more priority to reduce U value ,thus a lower U value specification in DGU is selected. The U value is reduced by 82.5 % from existing single glass unit. The VLT condition is above moderate , while the SC vaue remains the same as existing case.

- Windows & Curtain Wall & Spider glazing
  Saint Gobain SGG Cool-lite (6mm -16mm air gap with 90 % argon gas -6mm)

Case 4

The glass selected in this case is considering a lower U and SC value with moderate VLT specification. The SC value is reduced by around half from the existing case scenario, while U value is reduced by around 70%.

- Windows & Curtain Wall & Spider glazing
  Saint Gobain SKN (Cool-lite) (6mm solar coated face 2 -12mm air gap-6mm glass)

Case 5

The glass selected is as per recommendation by ECBC for WWR for 50-60%, where minimum VLT of 0.13 and max SC and U-value of 0.20 & 3.3 W/m2K respectively for warm & humid climate.

- Windows & Curtain Wall & Spider glazing
  Saint Gobain Aquamarine (6 mm solar coated-12mm air gap-6mm planitherm low-e coated)

Glass case scenario	U value (W/m^{2}K)	Shading Coffecient (SC)	VLT Coeffecient	Remarks
1-Existing	5.73	0.26	0.42	Spider glazing glass (U- 5.5 W/m^{2}K , SC-0.92, VLT-0.87)
2	1.77	0.62	0.75	Spider glazing glass (U- 5.5 W/m^{2}K , SC-0.92, VLT-0.87)
3	1	0.43	0.70	
4	1.6	0.26	0.40	
5-ECBC	1.76	0.16	0.14	

Table 6.2-3 Alternative Glazing Scenario Specification

6.2.4 External Shading Scenario

The building having entire west side glazed units and openable windows in east are the two scenarios where shading can be an effective component. These two side (east –west) need to be shaded from the low angle sun of summer in east & west which will cause overheating and glare problems. The north side curtain wall and windows need not be shaded due to reduce direct sola+r radiation.

Case 1

Each standard window size is 1500mm x 1500mm, thus in order to have an effective shading blocking the low angle sun, vertical fins on both sides along the height is selected. Thus outwrard fin projection of 600mm with spacing of 1500mm on all east side (total-49 windows) is considered for analysis.

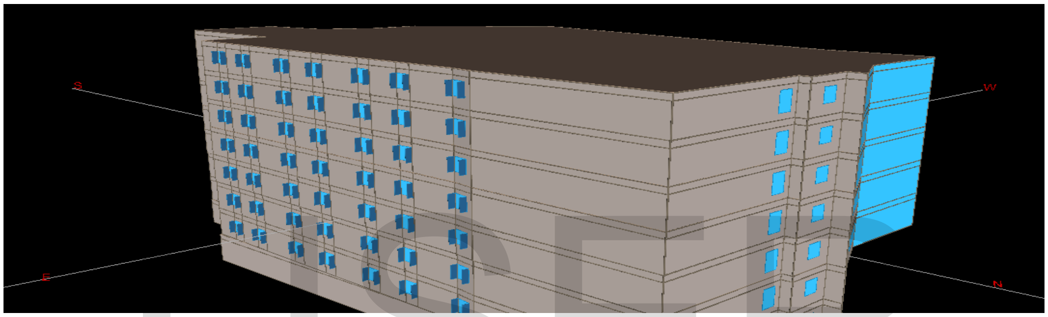


Figure 6.2-2 East Side Windows Vertical Fins

Case 2

The west glazed side (curtain wall) with storey height glazing (3600mm) and the bottom curve shape with spandrel and glass panel are shaded with help of vertical fins. The vertical fins and the unit are 1500mm apart , with outward projection of 600mm.

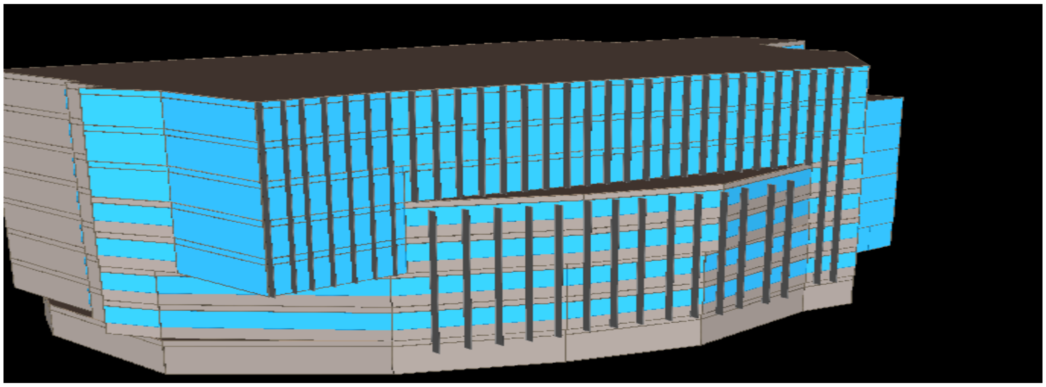


Figure 6.2-3 West side curtain wall vertical

7. ENERGY AND COST ANALYSIS

7.1 Overview & Validation of Simulation

This chapter presents the final results for the energy simulation carried for the research considering different scenarios. Thus it gives results for the individual breakup of cooling, ventilation, pumps & lighting loads. The analysis further extends to in-cooperate financial aspect of the modified changes to present a payback analysis and the commercial benefits of the modified changes.

The conversion rate from Indian national rupee to US dollar is 70 (1 INR*70= 1 USD)

Checking the existing case model which has to be in acceptable range with the real energy consumption values, so as to correctly validate the modified case scenarios. Below are the latest half yearly (2018) results for real and simulated energy consumptions. The simulated value predicted corresponds nearly to the real time value. (Net accuracy- about 1.75 % less than real value.) * **Energy Consumption Report for the building in Appendix C**

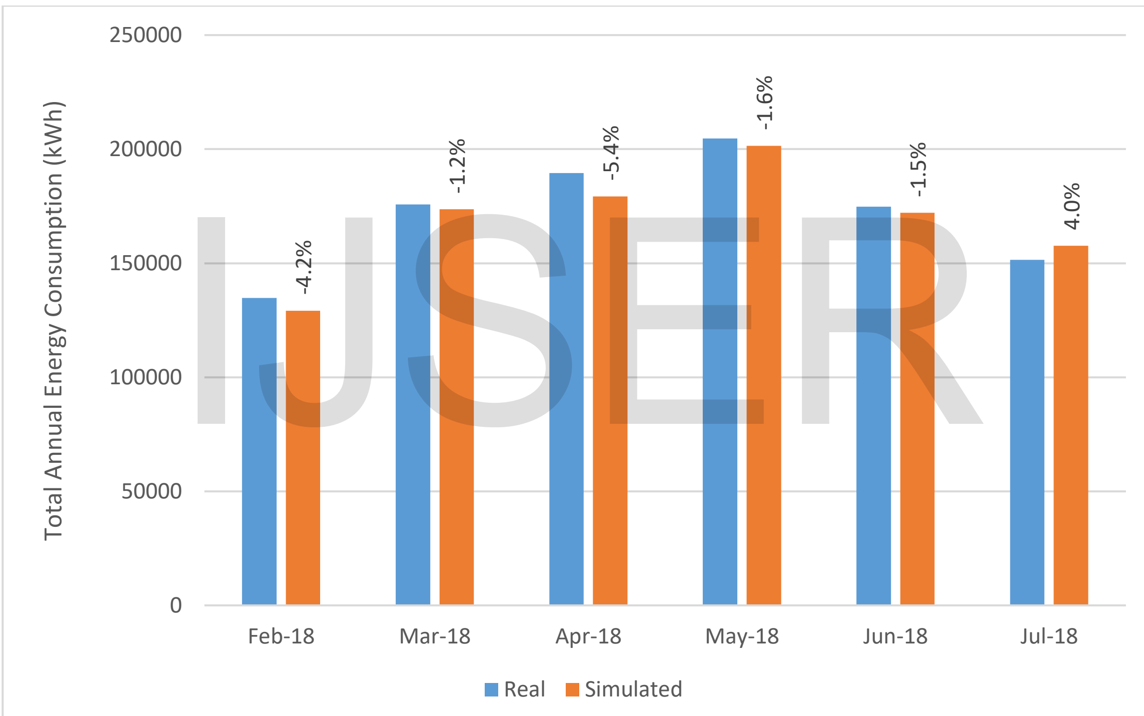


Figure 7.1-1 Real v/s Simulated Energy Consumption (Half yearly 2018)

7.2 Energy Consumption & Payback Analysis

The design case scenarios can be arranged with many combinations, thus in order to highlight the effect of roof, wall and glass with the respect to energy consumption, they are separately analysed and finally the stated case scenarios are analysed.

7.2.1 Roof Scenario Energy Consumption & Payback period

The analysis below is considering that the existing wall and glass specification remains the same as existing case scenario and only the roof specification is changed to analyse the impact.

1. The modification in the roof resulted in decrease consumption in space cooling by around 2.2% from case 1 to 5 due to reduction in internal temperature as compared to case 1 because of increase in thermal resistance. Along with it ventilation fans, pumps and heat rejection from air condition reduced by around 2.9 %. 0.5% & 2.9 % respectively from case 1 to case 5.
2. The case 4 & 5 (average saving – 1.04%) with insulation results in higher energy savings of about 2.5 times from average of case 2 and 3 having no insulation.
3. The major reduction observed is between February –June, where an average 3.5% of cooling loads can be reduced in case 5 from existing scenario. In March the cooling reduction of 5 % is found to be the most significant energy reduction.
4. Since artificial lighting and miscellaneous equipment including elevators were independent with heat change, it has constant value of 445500 & 311400 kWh respectively.

Thus changing the roof as per case 5 (ECBC case) has potential for annual energy reduction of about 19900 kWh (1.1%) or 9.3 kWh/m^2 of roof from case 1.

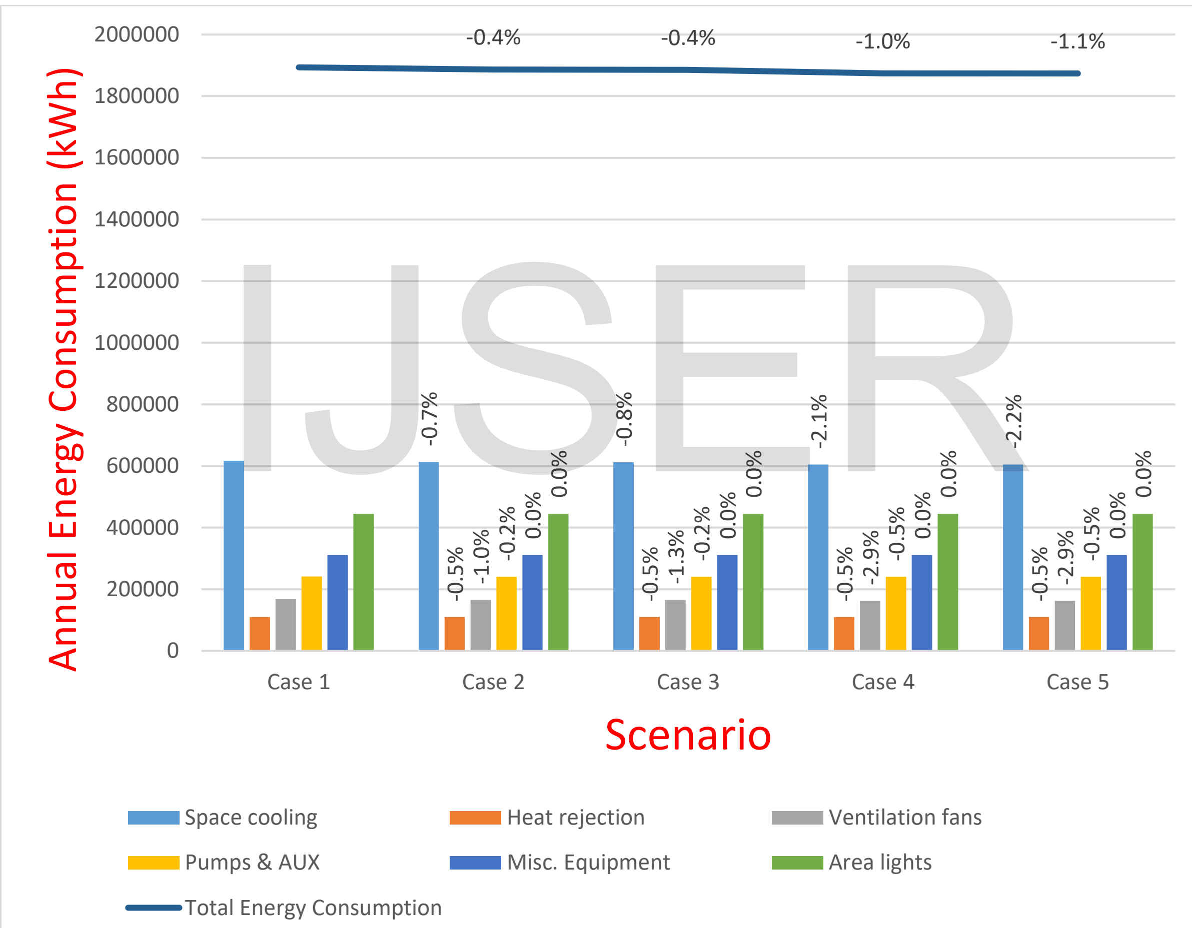


Figure 7.2-1 Annual Energy Consumption with change in Roof Specification

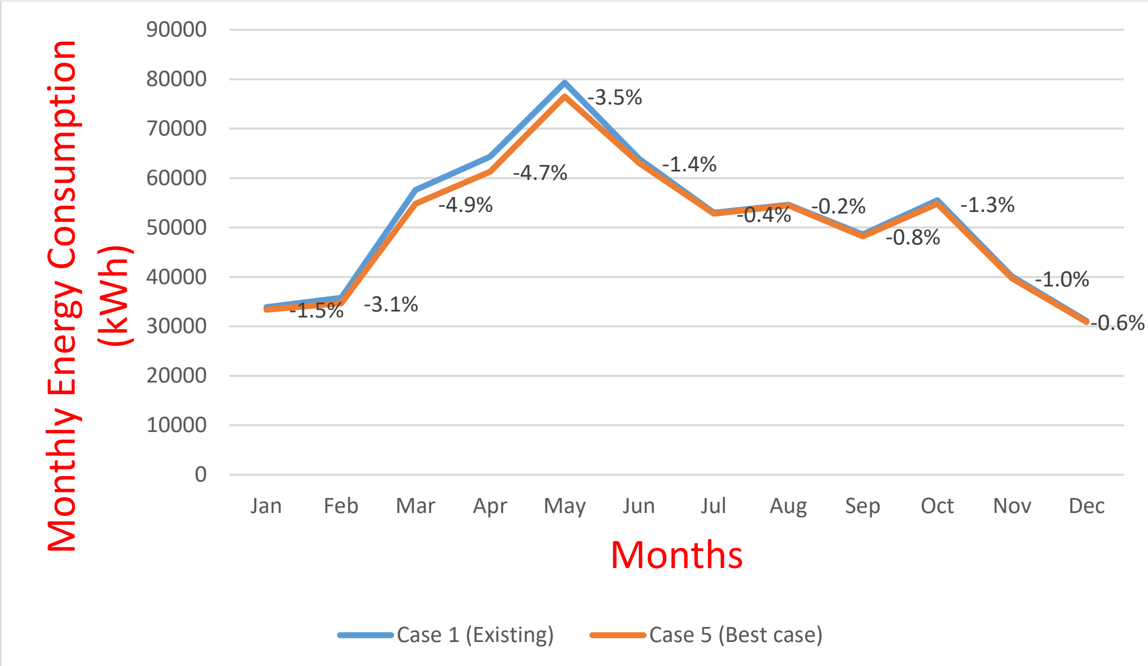


Figure 7.2-2 Roof Scenario Monthly energy consumption for cooling loads (Case 1 v/s Case 5)

Payback Analysis

Below is the payback analysis calculated for the modified cases from the existing case scenario.

Scenario 2 & 3 having long payback period of more than 10 is not an ideal economic solution. Thus when insulation is introduced in the scenario (case 4 & 5), the payback period is reduced significantly implying the use of insulation for optimized thermal comfort and economic consideration.

Scenario 5 having the highest initial investment of around 40000 USD, results in saving of around 3150 USD/yr. , while scenario 4 with 12 % less investment than scenario 5 , results in a lower payback period of 5 years, making scenario 4 an economic ideal solution.

	Case 1	Case 2	Case 3	Case 4	Case 5
Total sq.m	2137	2137	2137	2137	2137
Cost /sq.m	9	16	19	17	19
Total Cost (USD)	18669	33957	39641	35273	39911
Additional cost from case1 (USD)		15288	20973	16604	21242
Annual Energy savings from case 1 (kWh)		6900	8500	20300	20900

Annual Energy savings(USD) @ 0.15 USD/kWh		1035	1275	3045	3135
Payback Period (Years)		14.8	16.4	5.5	6.8

Table 7.2-1 Payback Period Calculation for Roof Scenario

7.2.2 External Wall Scenario Energy Consumption & Payback period

The wall specification are changed considering a constant existing (case 1) glass and roof specification. The analysis is about symmetrical to the one with roof scenarios.

1. Scenario 4 is with highest energy saving where lowest U value of 0.42 W/m^2K is prescribed with existing 200mm Brick wall with exterior insulation system finished with plaster. The annual cooling reduction is 2.80 % , while ventilation fans, pumps and heat rejection from air condition reduced by around 2.9 %. 1.85% & 2.9%.
2. The months where energy savings for cooling were the the summer months where average temperature is about more than 30°C most of the time, the cooling reduction in March is 4.5 % (case 4) , while average cooling savings in summer is 3.6 % from existing case.
3. In both case 4 & 5, resulting in energy saving in cooling of more than 2% where insulation is been used which implies the effectiveness of insulation in reduced energy consumption.
4. The electrical energy consumption from lighting and any other miscellinous equipment (elevators) have no effect with changes.

Thus changing the roof as per case 4 has potential for annual energy reduction of about 25000 kWh (1.3%) or 9.6 kWh/m^2 of wall from case 1

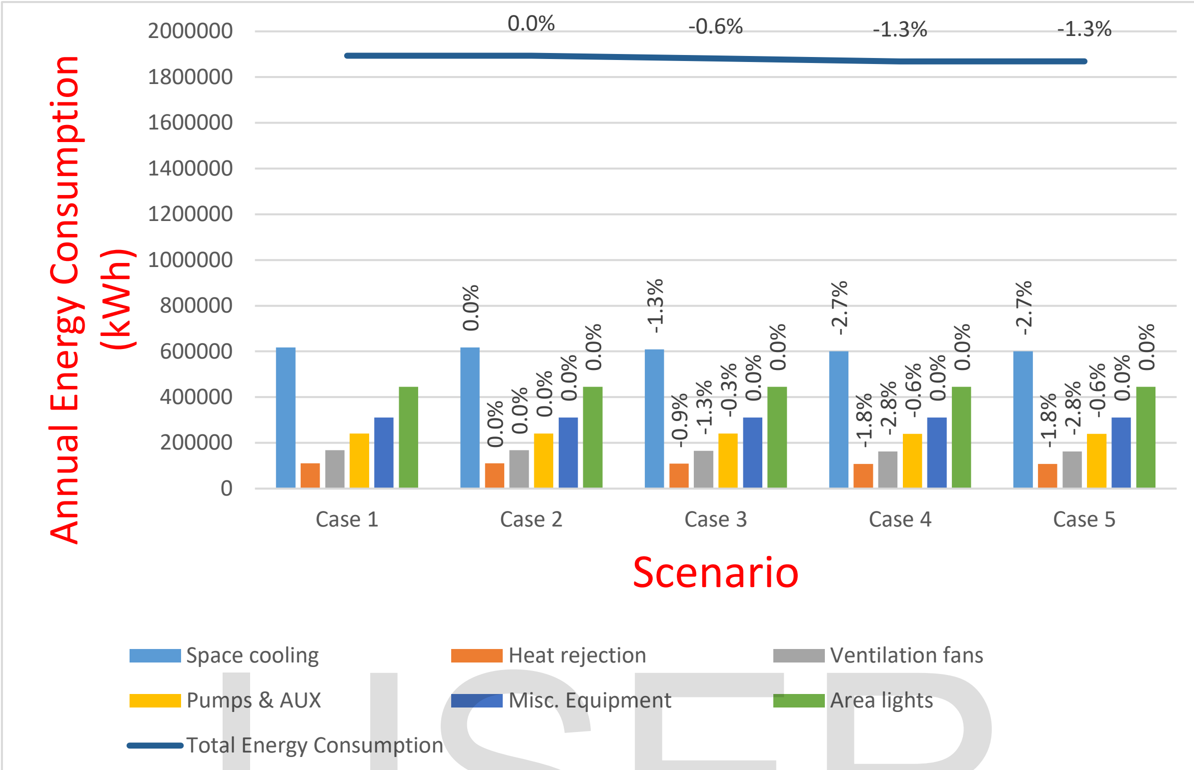


Figure 7.2-3 Total Energy Consumption with change in External wall Specification

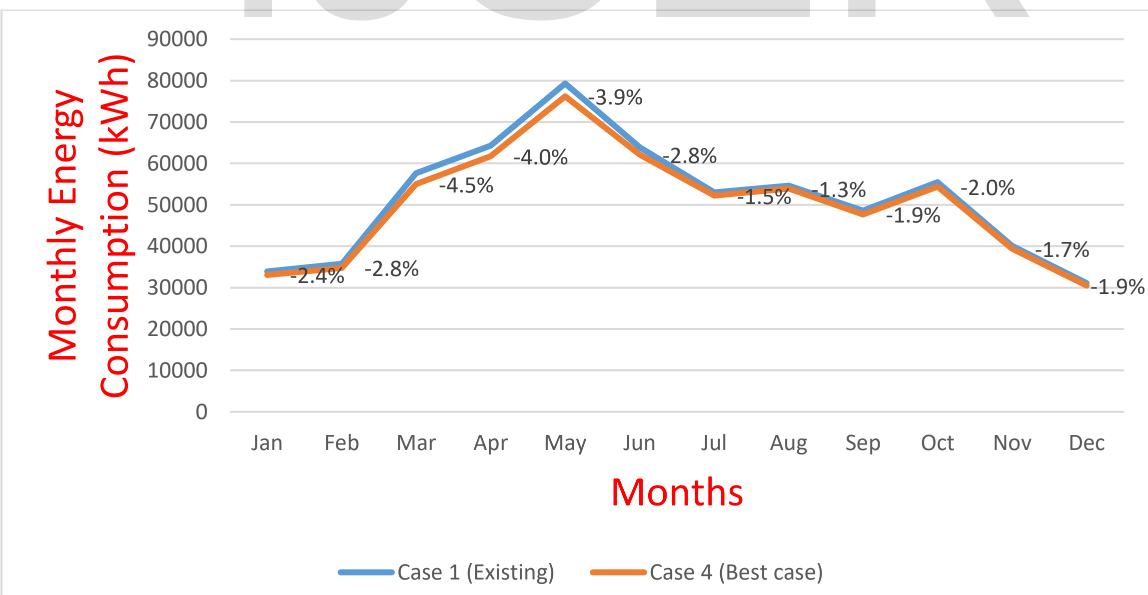


Figure 7.2-4 External Wall Scenario Monthly energy consumption for cooling loads (Case 1 v/s Case 4)

Payback Analysis

	Case 1 & 2	Case 3	Case 4	Case 5
Total sq.m	2616	2616	2616	2616
Cost /sq.m	12	17	20	22
Total Cost (USD)	31716	45320	51860	56676
Additional cost from case1 (USD)		13604	20143	24959
Energy savings from case 1 (kWh)		12100	25000	24800
Energy savings @ 0.15 USD/kWh		1815	3750	3720
Payback Period (Years)		7.5	5.4	6.7

Table 7.2-2 Payback Period Calculation for External Wall Scenario

All the below case shows a payback period of less than 10 years, thus implying an economic solution for energy reduction through modified external wall. The best economic Scenario along with providing thermal comfort is Case 4, which results in payback period of around 5.5 years.

7.2.3 Glazing Scenario Energy Consumption & Payback period

The analysis below is considering that the existing roof and wall specification remains the same as existing case scenario and only the glass specification is changed to analyse the impact.

1. The energy consumption output varies conversely for cooling and lighting loads. It is evident from figure 7.2-5 that changing glass specification which reduces cooling and ventilation load, increases the lighting load. The case scenario 5 where lowest SC glass of 0.16 is considered has around saving of 4.1 % from existing case for cooling as, but the lighting loads increases by 5.6%. The vice versa is seen in scenario 2 where maximum VLT of 0.75 is considered which gives saving of around 5% for lighting load as visible from existing case but increases cooling load by 2%.
   Thus with lower SC, the light is reflected back by glass which although reduces the infrared light which causes heat transfer but also blocks the visible light penetration, thus increasing the artificial light loads.

2. It is analysed from figure 7.2-5 by comparing scenario 4 and 2 that a reduce SC and U value in case 4 has more overall savings as compared to case 2 with higher VLT. The reason being space cooling is the highest energy consumption component, having more scope for energy reduction than lighting load. Also, considering the width of the office space of around 40m, the light penetration for a storey height glazing unit of 3.6 m (west side) and opposite side east with openable windows of 1.5 m height will have a combine daylight penetration of around 2.5 times the height (Office planning handbook CPWD, 2013) , i.e- 13 m which leaves around rest of the 2/3 rd part of the office being non-daylit, which will rely on artificial lighting for most part of the day.

3. Thus the reduced SC for glass in case 5 providing the best results for cooling loads , reduces the air conditioning loads in summer (Feb- June) by an average 4.75 % (Fig 7.2-6) , with best results observed in February.

4. The artificial lighting load in case 2 has average annual saving of 5.1 %, mostly these increase savings are observed in summer and winter periods due to clear sky condition as compared to months from Monsoon rain period July- October due to overcast condition.

5. Also , it is evident from comparing case 3 & 4 where direct heat transfer (SC) in tropical Indian climate is more important than U –factor as energy savings in case 4 is 2.4 % while in case 3 it is 1.6% , thus it is 50 % more effective.

Thus changing the glazing as per case 4 has potential of net energy reduction of about 46300 kWh (2.4%) or 15 kWh/m^2 of glazing from case 1.

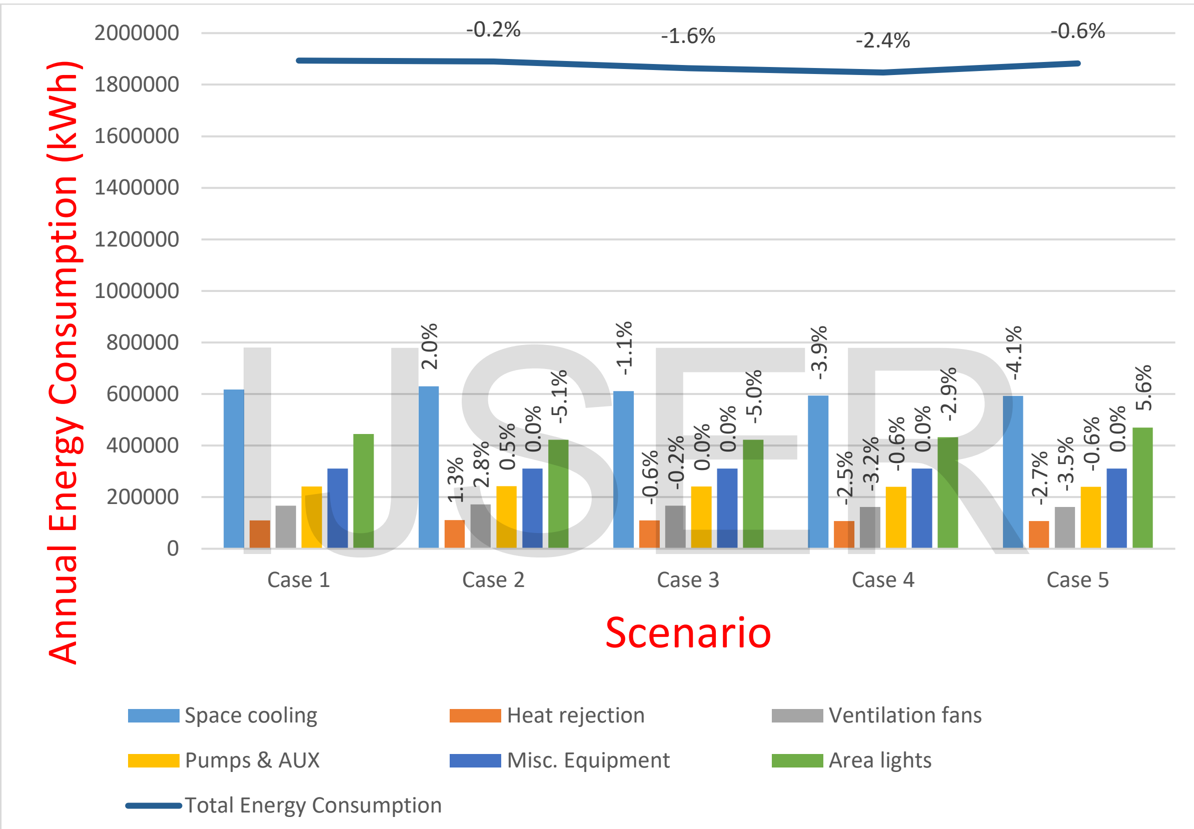


Figure 7.2-5 Total Energy Consumption with change in Glazing Specification

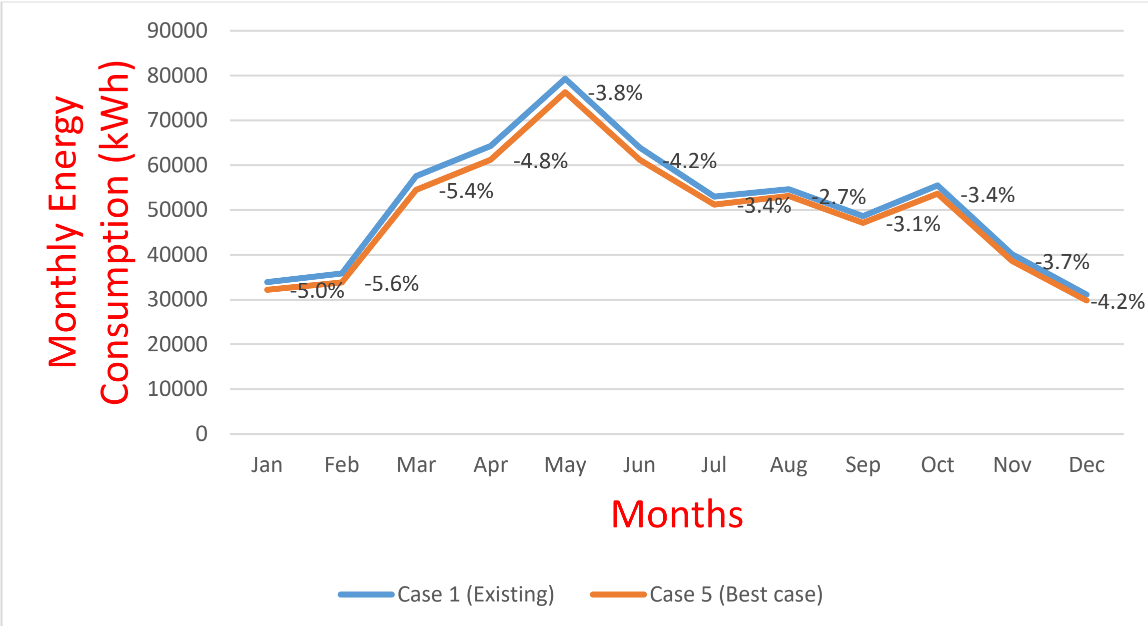


Figure 7.2-6 Glazing Scenario Monthly energy consumption for cooling loads (Case 1 v/s Case 5)

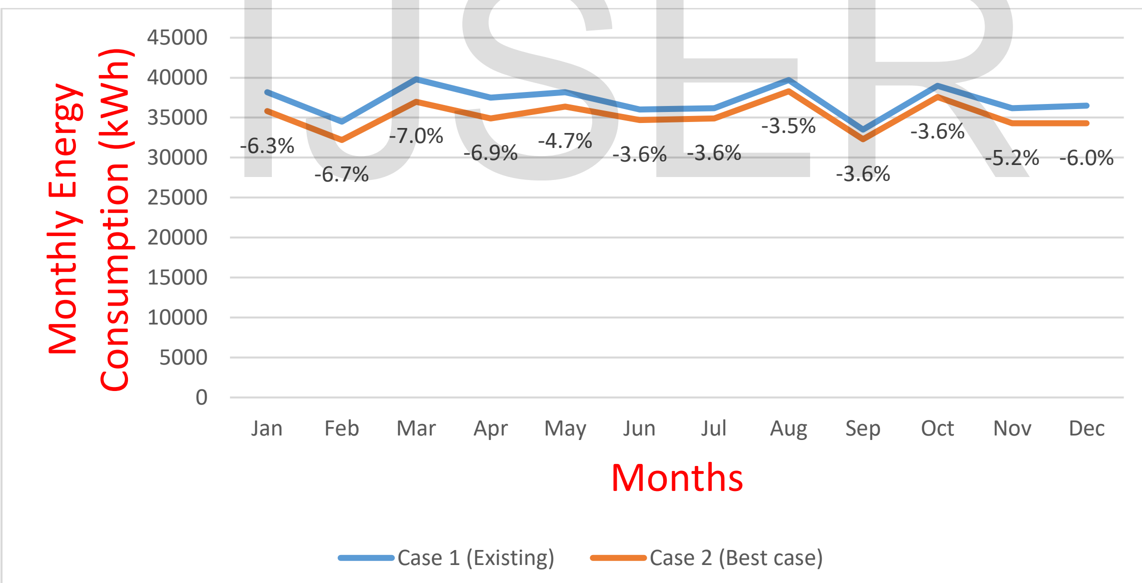


Figure 7.2-7 Glazing Scenario Monthly energy consumption for artificial lighting loads (Case 1 v/s Case 2)

Below is a payback analysis for glazing scenario analysing the commercial effect on glass modification. The glass rates considered below are basic saint gobain rates for India, considering all glasses are toughened. The total cost is considering all the glass which are used in windows, curtain wall & spider glazing.

Payback Analysis

In order to analyse the cooling and lighting payback associated with glass, the analysis is further differentiated considering HVAC & lighting energy savings.

	Case 1	Case 2	Case 3	Case 4	Case 5
Total sq.m	2845	2845	2845	2845	2845
Cost /sq.m	14.6	33.9	33.6	35	32.2
Total Cost (USD)	41537	96355	95592	99575	91609
Additional cost from case1 (USD)		54818	54055	58038	50072
HVAC Payback					
Annual Energy savings(USD) @ 0.15 USD/kWh		-2940	1155	4440	5325
Payback Period (Years)		-18.7	46.9	13.1	9.4
ARTIFICIAL LIGHTING PAYBACK					
Annual Energy savings(USD) @ 0.15 USD/kWh		3420	3330	1935	-3750
Payback Period (Years)		16	16.3	30	-13.4
OVERALL PAYBACK					
Annual Energy savings(USD) @ 0.15 USD/kWh		375	4485	6375	1575
Payback Period (Years)		146.4	12.1	9.1	31.9

Table 7.2-2 Payback Period Calculation for Glazing Scenario

- Comparing the HVAC return , which is best for case 5 around 9.5 years having the lowest SC value, but at the same time due to reduce VLT, the annual electrical lighting cost increases by 3750 USD.
- In all the scenario the lighting payback is above 15 years, thus even glass with better VLT specification is not an economical ideal solution for electrical savings.
- Although the cost for glass 4 comes out to be highest by around 2.5 times the cost for existing case, the overall payback calculated of 9 years is the lowest among all the modified cases.

7.2.4 External Shading device Scenario Energy Consumption

This scenario analyses the changes in the energy consumption of existing model for external shading device. Below is comparison between existing model and alternate 2 case (Case 1 – East side vertical window fins, Case 2 – West side curtain wall shading)

1. The west side curtain wall shading device has potential for annual cooling energy reduction by 1.33 %. A combined energy cooling savings with both the case as compared to non-shaded building is around 2%. The maximum energy savings is observed between Feb-June where a combined east & west shading results in 2.9 % cooling reduction.
2. The major effect of shades on reduce cooling load is due to obstructing the direct heat transfer for late morning period on east windows and west side shades are useful for late afternoon period. The effect of glare can also be minimized as the vertical shades cut out the summer sun having a lower horizontal angle in east-west direction.
3. Thus the shades reduce an annual average of 15 % of direct solar heat through glazing unit.
4. Thus shading on east-west direction glazing results in annual energy savings of 20620 kWh, thus saving around 3100 USD annually

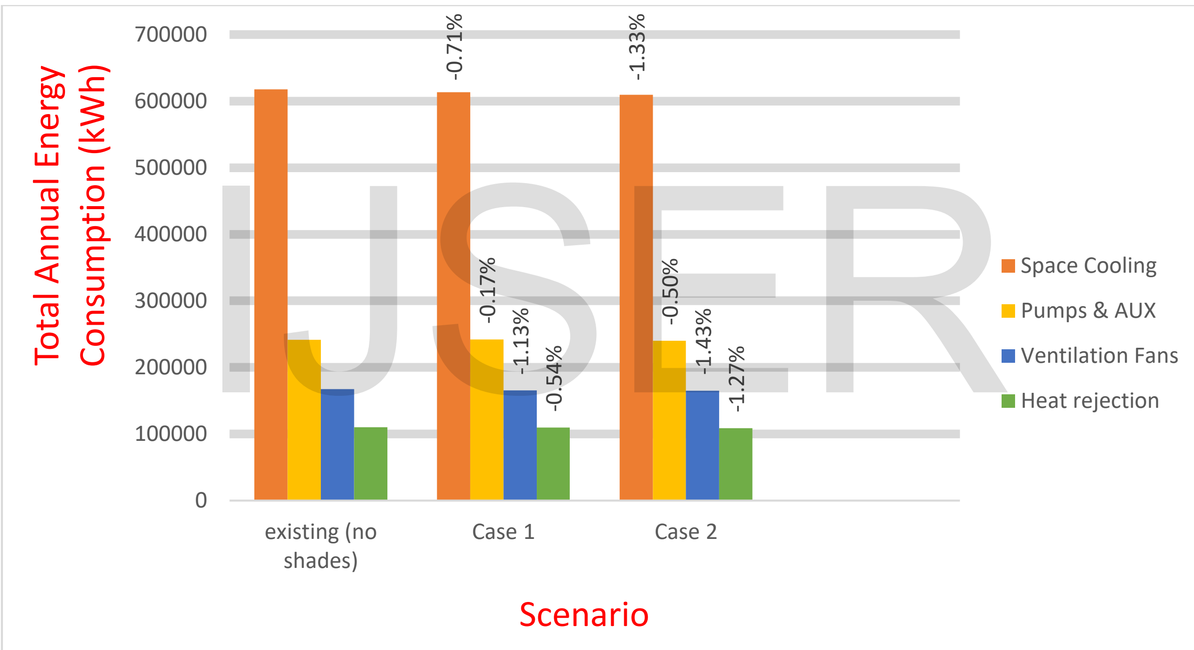


Figure 7.2-8 Energy consumption reduction for External shading device scenario

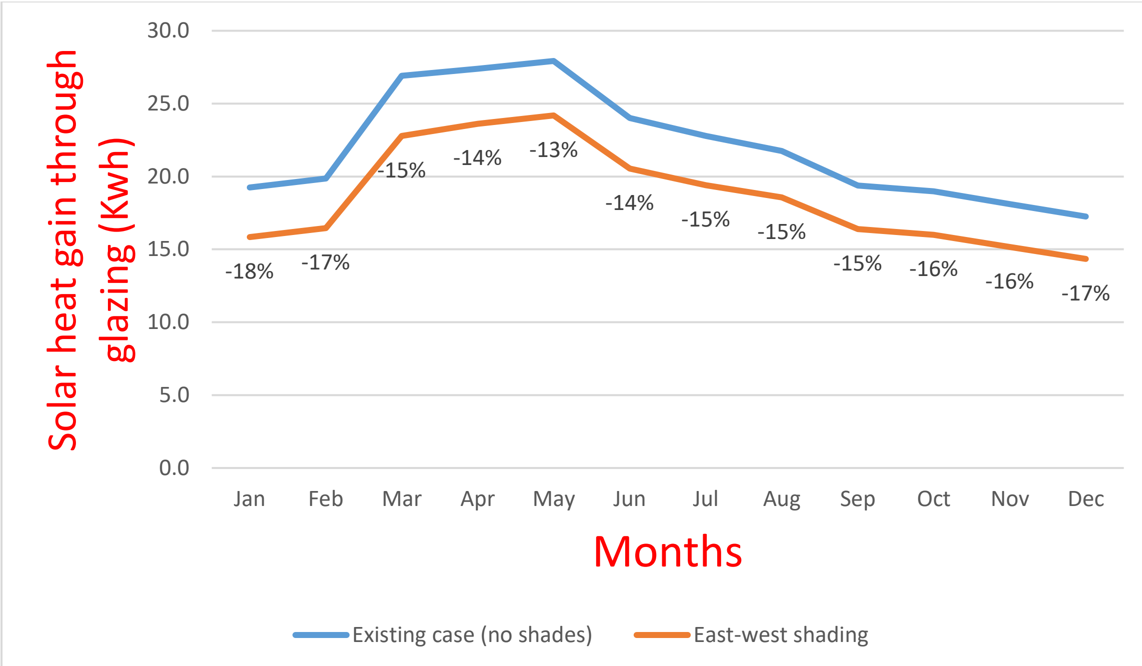


Figure 7.2-9 Solar heat gain reduction through external shading device

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8. CONCLUSION & SCOPE FOR FUTURE WORK

The final chapter concludes and summarises the results observed from the research and further recommends the best alternative scenario for energy savings. Further it recommends high performance building concept which is integration of passive strategy, effective building envelope & efficient active system.

8.1 Conclusion

This research is carried for energy reduction measures through building envelope, while maintaining the internal comfort for the employees. The combined net energy savings through selecting best case scenarios among roof, wall, glazing & east-west shading is concluded to be **5.8 % per year**. The major energy reduction is observed in cooling loads especially in summer period (Feb-June), saving energy by **6.9% per year** from all the best case scenarios.

Thus it gives opportunity for client to increase the rentable space by 6% after refurbishment for 12600 m^2 usable space (75% of 16800 m^2 for all 7 floors). Thus increasing the overall rent by around 880 USD/month or 10560 USD /yr.
(*Calculation in Appendix D)

Below are the individual component conclusion

Exterior wall	The existing building having 48% of exterior wall area with major wall areas in east & south side, has to be thermally resistive especially in summer period where maximum temperature can be around 35-40°C. The energy reduction is linearly proportional to reduce heat conductivity, and thus insulating the wall shows a thermally and economically an effective solution for energy reduction. Although XPS Insulation having very low thermal conductivity, it is prone to combustion which adds to the disadvantage in high rise building. The payback of around 5 and half years is very satisfactory, if compared that wall would have at least around 20-30 years of life, which can yield a profit of 15 years at minimum. Best Case **Case 4 (15mm gypsum plaster- 200mm brick wall - 60 mm XPS Insulation – 15mm Cement plaster)**
Roof	The roof modification specifications are based on insulation as well as traditional cool roof methods. With energy savings of 9.3 kWh/m^2 from existing case, it also show about the same thermal and economic results as exterior wall scenarios, reflecting the use of insulation for significant energy reduction. Insulation not only provides a thermal and economic solution, it also reduces the additional dead load of the roof structure due to low density material as compared to any other thermal mass layer. Best case- **Case 5 (160 mm RCC- 60 mm XPS Insulation -75 mm inverted earthen pot – 20mm cement mortar)**
Glazing	The glass selection is the most complex as well as the most the energy saving potential component in building envelope. The conflicting parameters of SC & VLT for reducing energy in cooling and artificial lights respectively has to be correctly analysed depending on the requirement as well as potential measures for energy savings as per project. In tropical climates where heat is dominant on outside, the

	potential in reducing direct heat transfer (SC) is more beneficial than conduction heat transfer (U-value). The payback return of 9 years (case 4) analysed is more than that of roof and wall since as the glazing cost significantly increases with changes in specifications. But if considering the glass life of around 20 years for DGU as per Australian research (N.P Howard, J Burgess & C.Lim, 2007), the rest 11 years is an interest on the initial investment of 99575 USD. Best case- **Case 4** **SC- 0.26** **U value- 1.6 W/m^{2}K** **VLT- 0.40**
Shading	Both west-east side shading are recommended for reducing the direct heat transfer., Thus shading reduces the infrared penetration towards glazing unit , thus a moderate SC glass with high VLT coefficient can be selected for further overall reduction. Reduce cooling, ventilation & pumps energy consumption is observed.

8.2 Scope for Future Work

The above research only considers energy savings through modified effective building envelope, focusing majorly on reducing the heat transfer at the perimeter of the building.

Further strategy along with effective building envelope for energy savings are -Solar Passive & Active System.

- Solar Passive Approach
  The solar passive approach (i.e. – Change in Orientation, WWR, Natural Ventilation, Buffer Space, Location) may not be a feasible solution for already existing building.
  Passive approach along with effective building envelope is a preventive approach which reduces the building reliance on active system, thus reducing the energy consumption of HVAC & lighting system. Although the approach requires high investment as compared to active strategy, the long-time benefits is far significant than annual maintenance for active systems.

- Active System Approach
  The use of efficient and modernized active system (censors, high COP chillers, efficient ventilating system, and low energy consuming lighting system) is the other side of energy saving measures.
  Considered as curative approach where the thermal and visual comfort for the occupants is met in expense of reduced energy consumption through efficient active system.

Thus High performance building integrating passive, active strategy along with effective building envelope is a key all round approach for energy reduction in commercial spaces and thus recommends future research in this topic through live projects

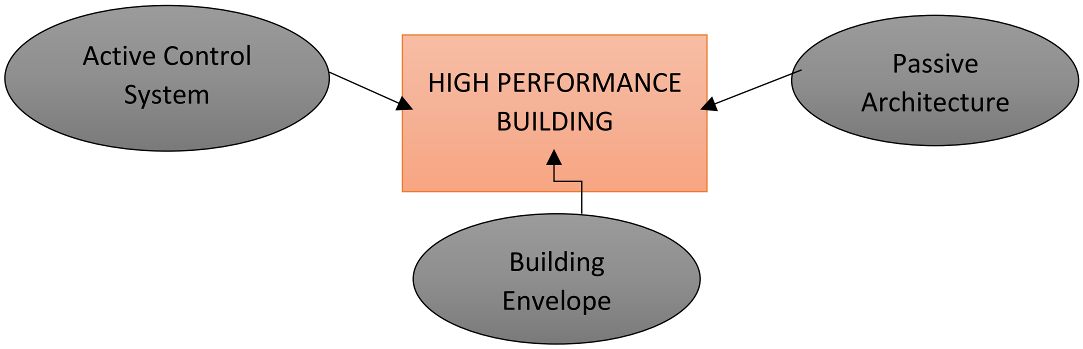

Figure 8.2-1 High Performance Building Components

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APPENDIX A – Thermal Value Calculation

The calculation equation and results for each scenario are described in Appendix A. The calculation is derived from Indian standard 3792. The value for material property (conductivity, specific heat density) are drawn from NBC, 2005 (SP-7) & CPWD, Integrated green design.

Thermal Resistance equation

R_T (thermal resistance) =l (thickness) /k (thermal conductivity)

R_i = internal surface resistance

$R_{e\ =}$ external surface reisstance

Total thermal resistance $R_T = R_i + R_1 + R_2 + \ldots R_N + R_e$

$U = 1/ R_T$

Thermal calculation for design scenarios

- ***SCENARIO 1***

Material	**Conductivity (W/m-k)**	**Thickness (m)**	**Thermal Resistance (m^2K/W)**	**Specific Heat (KJ/m³K)**	**Density (kg/m^3)**
Roof					
RCC	1.58	0.16	0.1	0.88	2288
Wall					
Cement plaster (outside)	0.721	0.015	0.02	0.84	1762
Burnt Brick	0.811	0.2	0.25	0.88	1820
Gypsum plaster (Inside)	0.512	0.015	0.03	0.96	1120
BS EN ISO 6946					
Roof	Thermal Resistance (m^2K/W)		**Wall**	Thermal Resistance (m^2K/W)	
External surface resistance	0.04		External surface resistance	0.04	
Internal surface resistance	0.10		Internal surface resistance	0.13	
Roof			**Wall**		
Total system Resistance(R_T)	0.24		Total system Resistance(R_T)	0.47	
U value	4.17		U value	2.12	

- ***SCENARIO 2***

Material	Conductivity (W/m-k)	Thickness (m)	Thermal Resistance (m^2K/W)	Specific Heat (KJ/m^3K)	Density (kg/m^3)
Roof					
Tile	0.798	0.025	0.03	0.88	1892
Lime concrete	0.73	0.1	0.14	0.88	1646
RCC (Inside)	1.58	0.2	0.13	0.88	2288
Wall					
Cement plaster (outside)	0.721	0.015	0.02	0.84	1762
Burnt Brick	0.811	0.2	0.25	0.88	1820
Gypsum plaster (Inside)	0.512	0.015	0.03	0.96	1120
BS EN ISO 6946					
Roof	Thermal Resistance (m^2K/W)		**Wall**	Thermal Resistance (m^2K/W)	
External surface resistance	0.04		External surface resistance	0.04	
Internal surface resistance	0.10		Internal surface resistance	0.13	
Roof			**Wall**		
Total system Resistance(R_T)	0.44		Total system Resistance(R_T)	0.47	
U value	2.3		U value	2.12	

- ***SCENARIO 3***

Material	Conductivity (W/m-k)	Thickness (m)	Thermal Resistance (m^2K/W)	Specific Heat (KJ/m^3K)	Density (kg/m^3)
Roof					
Tile	0.798	0.025	0.03	0.88	1892
Brick Bat coba	0.625	0.11	0.17	0.88	1820
RCC (Inside)	1.58	0.25	0.16	0.88	2288
Wall					
Cement plaster (outside)	0.721	0.015	0.02	0.84	1762
Burnt Brick	0.811	0.115	0.14	0.88	1820
Air Cavity (BS EN ISO 6946)			0.18		
Burnt Brick	0.811	0.2	0.25	0.88	1820
Gypsum plaster (Inside)	0.512	0.015	0.03	0.96	1120
BS EN ISO 6946					
Roof	Thermal Resistance (m^2K/W)		**Wall**	Thermal Resistance (m^2K/W)	
External surface resistance	0.04		External surface resistance	0.04	
Internal surface resistance	0.10		Internal surface resistance	0.13	

Roof			**Wall**		
Total system Resistance(R_T)	0.50		Total system Resistance(R_T)	0.79	
U value	2		U value	1.27	

- ***SCENARIO 4***

Material	**Conductivity (W/m-k)**	**Thickness (m)**	**Thermal Resistance (m^2K/W)**	**Specific Heat (KJ/m^3K)**	**Density (kg/m^3)**
Roof					
Tile	0.798	0.025	0.03	0.798	1892
XPS Insulation	0.029	0.06	2.07	1.34	35
RCC (Inside)	1.58	0.16	0.10	0.88	2288
Wall					
Cement plaster (outside)	0.721	0.015	0.02	0.84	1762
XPS Insulation	0.029	0.06	2.07	1.34	35
Burnt Brick	0.811	0.2	0.25	0.88	1820
Gypsum plaster (Inside)	0.512	0.015	0.03	0.96	1120
BS EN ISO 6946					
Roof	Thermal Resistance (m^2K/W)		**Wall**	Thermal Resistance (m^2K/W)	
External surface resistance	0.04		External surface resistance	0.04	
Internal surface resistance	0.10		Internal surface resistance	0.13	
Roof			**Wall**		
Total system Resistance(R_T)	2.34		Total system Resistance(R_T)	2.54	
U value	0.43		U value	0.40	

International Journal of Scientific & Engineering Research Volume 11, Issue 9, September-2020
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Scenario 5

Material	**Conductivity (W/m-k)**	**Thickness (m)**	**Thermal Resistance (m^2K/W)**	**Specific Heat (KJ/m^3K)**	**Density (kg/m^3)**
Roof					
Cement mortar	0.719	0.02	0.03	0.92	1648
Inverted earthen pot	0.26	0.075	0.29	-	-
XPS Insulation	0.029	0.06	2.07	1.34	35
RCC (Inside)	1.58	0.160	0.10	0.88	2288
Wall					
Cement plaster (outside)	0.721	0.015	0.02	0.84	1762
Burnt Brick	0.811	0.1	0.12	0.88	1820
XPS Insulation	0.029	0.05	1.72	1.34	35
Burnt Brick	0.811	0.15	0.18	0.88	1820
Gypsum plaster (Inside)	0.512	0.015	0.03	0.96	1120
BS EN ISO 6946					
Roof	Thermal Resistance (m^2K/W)		**Wall**	Thermal Resistance (m^2K/W)	
External surface resistance	0.04		External surface resistance	0.04	
Internal surface resistance	0.10		Internal surface resistance	0.13	
Roof			**Wall**		
Total system Resistance(R_T)	2.63		Total system Resistance(R_T)	2.24	
U value	0.38		U value	0.44	

APPENDIX B – Simulation Results

The results are summarized from the simulation run on eQuest by considering the case and scenarios of modified building envelope. The monthly and total results for each changing scenario is summarized. The miscellaneous equipment's have a constant energy consumption as they are un-affected by modified building envelope.

All the energy consumption values are kWh*1000

- **Roof Scenario**

  The roof thermal resistance values were changed as per case, keeping glass and wall specification the same as existing case 1.

	Case	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total (kWh* 1000)
Space cool	1	33.9	35.8	57.6	64.3	79.3	63.9	53	54.6	48.6	55.5	40.1	31.1	**617.6**
	2	33.7	35.4	56.6	63.4	78.5	63.7	52.9	54.6	48.4	55.2	40	31	**613.4**
	3	33.6	35.3	56.5	63.1	78.3	63.6	52.9	54.6	48.4	55.2	39.9	31	**612.4**
	4	33.4	34.7	54.9	61.3	76.6	63	52.8	54.5	48.2	54.8	39.7	30.9	**604.7**
	5	33.4	34.7	54.8	61.3	76.5	63	52.8	54.5	48.2	54.8	39.7	30.9	**604.4**
Heat Rejection	1	5.5	5.6	8.6	9.8	13.8	12.5	10.6	11	9.6	10.7	7.2	5.3	**110.1**
	2	5.5	5.5	8.5	9.7	13.7	12.5	10.5	11	9.6	10.6	7.1	5.2	**109.6**
	3	5.5	5.5	8.5	9.7	13.7	12.4	10.5	11	9.6	10.6	7.1	5.2	**109.5**
	4	5.5	5.4	8.3	9.5	13.5	12.4	10.5	11	9.5	10.6	7.1	5.2	**108.5**
	5	5.5	5.4	8.3	9.5	13.5	12.4	10.5	11	9.5	10.6	7.1	5.2	**108.5**
Vent. Fans	1	12.1	11.9	19.1	20.7	19.8	13.2	11.8	12.8	10.8	12.9	11.4	11.1	**167.6**
	2	12.1	11.8	18.7	20.1	19.4	13.1	11.8	12.8	10.8	12.8	11.4	11.1	**165.9**
	3	12.1	11.8	18.6	20	19.4	13.1	11.8	12.7	10.8	12.8	11.4	11.1	**165.5**
	4	12.1	11.7	17.9	19.1	18.7	13	11.8	12.7	10.7	12.8	11.4	11.1	**162.9**
	5	12.1	11.7	17.9	19.1	18.6	13	11.7	12.7	10.7	12.7	11.4	11.1	**162.8**
	1	19.7	17.9	21.3	21.1	23.2	20.5	19.8	21.6	17.9	20.7	18.8	18.8	**241.4**

Pumps & Aux	2	19.7	17.9	21.1	21	23.1	20.5	19.8	21.6	17.9	20.7	18.8	18.8	**240.9**
	3	19.7	17.9	21.1	20.9	23	20.5	19.8	21.6	17.9	20.7	18.8	18.8	**240.8**
	4	19.7	17.9	21	20.7	22.8	20.4	19.8	21.6	17.9	20.7	18.8	18.8	**240.1**
	5	19.7	17.9	21	20.7	22.8	20.4	19.8	21.6	17.9	20.7	18.8	18.8	**240.1**
Misc. Equip	1,2,3,4,5	26.1	23.6	27.2	26	27.2	26	26.1	28.2	23.9	27.2	24.9	25.1	**311.4**
Area lights	1,2,3,4,5	38.2	34.5	39.8	37.5	38.2	36	36.2	39.7	33.5	39	36.2	36.5	**445.4**

- **Wall Scenario**

  The roof thermal resistance values were changed as per case, keeping glass and roof specification the same as existing case 1.

	Case	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total(kWh*1000)**
Space cool	1,2	33.9	35.8	57.6	64.3	79.3	63.9,	53	54.6	48.6	55.5	40.1	31.1	**617.6**
	3	33.5	35.3	56.3	63	77.8	63	52.6	54.3	48.1	54.9	39.8	30.8	**609.5**
	4	33.1	34.7	55	61.6	76.2	62.1	52.2	53.9	47.7	54.4	39.4	30.5	**600.8**
	5	33.1	34.8	55	61.7	76.2	62.1	52.2	53.9	47.7	54.4	39.4	30.5	**601**
Heat Rejection	1,2	5.5	5.6	8.6	9.8	13.8	12.5	10.6	11	9.6	10.7	7.2	5.3	**110.1**
	3	5.5	5.5	8.5	9.7	13.6	12.4	10.5	10.9	9.5	10.6	7.1	5.2	**109.1**
	4	5.4	5.4	8.3	9.5	13.4	12.2	10.5	10.9	9.5	10.5	7.1	5.2	**108.1**
	5	5.4	5.4	8.3	9.5	13.4	12.2	10.5	10.9	9.5	10.5	7.1	5.2	**108.1**
Vent. Fans	1,2	12.1	11.9	19.1	20.7	19.8	13.2	11.8	12.8	10.8	12.9	11.4	11.1	**167.6**
	3	12	11.8	18.7	20.2	19.3	13	11.7	12.7	10.7	12.8	11.4	11.1	**165.4**
	4	12	11.6	18.1	19.5	18.7	12.8	11.7	12.7	10.7	12.7	11.3	11.1	**162.9**
	5	12	11.6	18.1	19.6	18.7	12.9	11.7	12.7	10.7	12.7	11.3	11.1	**162.9**
Pumps & Aux	1,2	19.7	17.9	21.3	21.1	23.2	20.5	19.8	21.6	17.9	20.7	18.8	18.8	**241.4**
	3	19.7	17.9	21.1	20.9	22.9	20.4	19.8	21.6	17.9	20.7	18.8	18.8	**240.6**
	4	19.7	17.9	21	20.8	22.7	20.3	19.7	21.6	17.9	20.7	18.8	18.8	**239.9**

	5	19.7	17.9	21	20.8	22.7	20.3	19.7	21.6	17.9	20.7	18.8	18.8	**239.9**
Misc. Equip	1,2,3,4,5	26.1	23.6	27.2	26	27.2	26	26.1	28.2	23.9	27.2	24.9	25.1	**311.4**
Area lights	1,2,3,4,5	38.2	34.5	39.8	37.5	38.2	36	36.2	39.7	33.5	39	36.2	36.5	**445.4**

- **Glazing Scenario**

The roof thermal resistance values were changed as per case, keeping wall and roof specification the same as existing case 1.

	Case	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total(kWh*1000)
Space cool	1	33.9	35.8	57.6	64.3	79.3	63.9	53	54.6	48.6	55.5	40.1	31.1	**617.6**
	2	34	36.2	59.4	66.4	82	65.7	53.9	55.2	49.2	56.2	40.5	31.2	**629.8**
	3	32.8	34.8	57.1	64	79.8	63.7	52.3	53.9	48	54.8	39.3	30.3	**610.9**
	4	32.2	33.8	54.7	61.5	76.6	61.4	51.3	53.1	47.2	53.7	38.6	29.8	**593.8**
	5	32.2	33.8	54.5	61.2	76.3	61.2	51.2	53.1	47.1	53.6	38.6	29.8	**592.4**
Heat Rejection	1	5.5	5.6	8.6	9.8	13.8	12.5	10.6	11	9.6	10.7	7.2	5.3	**110.1**
	2	5.6	5.6	8.8	10.1	14.2	12.7	10.7	11	9.6	10.8	7.2	5.3	**111.5**
	3	5.4	5.4	8.6	9.8	13.9	12.5	10.5	10.9	9.5	10.6	7.1	5.1	**109.4**
	4	5.3	5.3	8.3	9.5	13.5	12.2	10.4	10.8	9.4	10.5	7	5.1	**107.3**
	5	5.3	5.3	8.3	9.5	13.4	12.1	10.4	10.8	9.4	10.5	7	5.1	**107.1**
Vent. Fans	1	12.1	11.9	19.1	20.7	19.8	13.2	11.8	12.8	10.8	12.9	11.4	11.1	**167.6**
	2	12.2	12.1	20	21.8	21.2	13.7	11.9	12.8	10.9	13.1	11.5	11.1	**172.3**
	3	12	11.7	19	20.7	20.2	13.3	11.7	12.7	10.7	12.8	11.3	11	**167.2**
	4	11.9	11.5	18	19.5	18.9	12.8	11.6	12.6	10.6	12.6	11.2	11	**162.2**
	5	11.9	11.4	17.9	19.4	18.8	12.8	11.6	12.6	10.6	12.6	11.2	11	**161.8**
Pumps & Aux	1	19.7	17.9	21.3	21.1	23.2	20.5	19.8	21.6	17.9	20.7	18.8	18.8	**241.4**
	2	19.7	17.9	21.6	21.4	23.4	20.7	19.9	21.6	17.9	20.8	18.8	18.8	**242.5**
	3	19.7	17.9	21.4	21.1	23.2	20.5	19.8	21.6	17.9	20.7	18.8	18.8	**241.5**

	4	19.7	17.9	21	20.8	22.8	20.2	19.7	21.6	17.9	20.7	18.8	18.8	**240**
	5	19.7	17.9	21	20.7	22.8	20.2	19.7	21.6	17.9	20.7	18.8	18.8	**239.9**
Misc. Equip	1,2,3,4 ,5	26.1	23.6	27.2	26	27.2	26	26.1	28.2	23.9	27.2	24.9	25.1	**311.4**
Area lights	1	38.2	34.5	39.8	37.5	38.2	36	36.2	39.7	33.5	39	36.2	36.5	**445.4**
	2	35.8	32.2	37	34.9	36.4	34.7	34.9	38.3	32.3	37.6	34.3	34.3	**422.6**
	3	35.9	32.2	37.1	35	36.4	34.8	35	38.4	32.3	37.6	34.3	34.3	**423.2**
	4	36.9	33.3	38.4	36.1	37.1	35.3	35.5	38.9	32.7	38.1	35	35.2	**432.5**
	5	40.2	36.3	41.9	39.6	40.6	38.2	38.4	42.2	35.5	41.2	38.1	38.4	**470.4**

- **Shading Scenario**

Energy Consumption-

	Case	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total(kWh*1000)**
Space cool	1	33.6	35.3	56.5	63.3	78.7	63.8	52.9	54.6	48.4	55.2	39.9	31	613.2
	2	33.5	35.3	56.3	62.7	77.8	63.3	52.6	54.3	48.3	54.8	39.7	30.8	609.4
Heat Rejection	1	5.5	5.5	8.5	9.8	13.7	12.5	10.5	11	9.6	10.6	7.1	5.2	109.5
	2	5.5	5.5	8.4	9.7	13.5	12.4	10.4	10.9	9.5	10.6	7.1	5.2	108.7
Vent. Fans	1	12.1	11.8	18.6	20.1	19.4	13.1	11.8	12.7	10.8	12.8	11.4	11.1	165.7
	2	12	11.8	18.7	20.1	19.3	13	11.8	12.7	10.5	12.8	11.4	11.1	165.2
Pumps & Aux	1	19.7	17.9	21.1	21	23	21.5	19.8	21.6	17.9	20.7	18.8	18.8	241.8
	2	19.7	17.9	21.1	20.9	22.7	20.4	19.6	21.6	17.9	20.8	18.8	18.8	240.2
Misc. Equip	1	26.1	23.6	27.2	26	27.2	26	26.1	28.2	23.9	27.2	24.9	25.1	311.4
Area lights	1	38.2	34.5	39.8	37.5	38.2	36	36.2	39.7	33.5	39	36.2	36.5	445.4

Solar Heat Gains

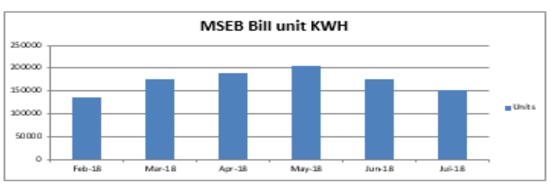
Case	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total (kWh)**
Existing (no shades)	19.3	19.9	26.9	27.4	27.9	24	22.8	21.8	19.4	19	18.1	17.3	263.8
East-west shades	15.8	16.5	22.8	23.6	24.2	20.5	19.4	18.6	16.4	16	15.2	14.3	223.3

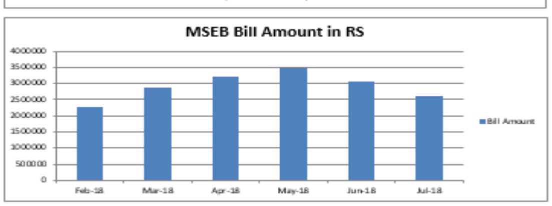
APPENDIX C – Energy Consumption Validated Result

The simulated model is validated through below half yearly 2018 total energy consumption report maintained by CBRE. (confidential)

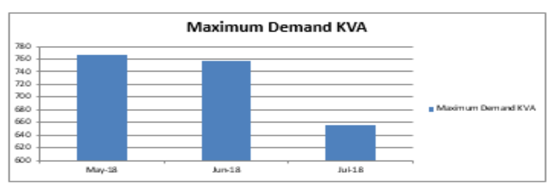
Utilities - Electricity

Bill Month	Feb-18	Mar-18	Apr-18	May-18	Jun-18	Jul-18
Units	134820	175780	189540	204720	174760	151540
Bill Amount	2292327	2892975	3215973	3491314	3056033	2593590

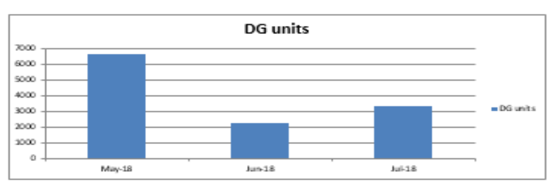




Maximum Demand KVA			
Bill Month	May-18	Jun-18	Jul-18
Maximum Demand KVA	766	757	656



DG set Units			
Chart Area	May-18	Jun-18	Jul-18
DG units	6584	2277	3338



Bill Month	Feb-18	Mar-18	Apr-18	May-18	Jun-18	Jul-18
Units	134820	175780	189540	204720	174760	151540
Bill Amount	2292327	2892975	3215973	3491314	3056033	2593590

APPENDIX D – Rent Calculation

Below is the calculation for approx. rent charged for the commercial space as per real estate agency, and the cost is converted to USD considering (1USD = 70 INR).

Current Cost USD /sq.m	**1.15**
Total work space for rent (m^2)	12600
Rent charged per month (USD/month)	14490
Increase cost USD/sq.m	1.22
New Rent charged per month (USD/month)	15372
Increase Rent (USD/month)	882