Retrofitting thermal performance of building envelope and extension of Secha Sadan, Bhubaneswar

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Abstract: The built environment is responsible for 40% of the global energy demand. Efforts are to be made in existing buildings, namely in office buildings, which are statistically more energy consuming than residential buildings. One of the main components of achieving a more sustainable built environment is to improve the performance of the existing building stock by retrofitting to increase the energy efficiency and improve quality of life (Low Carbon Innovation Coordination Group 2012). The retrofit of building envelope can help in saving 50–60% of the buildings' energy consumption used for HVAC purposes. Secha Sadan is a 50 year old government office building in Bhubaneswar. Proposing a building envelope retrofitting for this structure will not only help in reducing the energy consumption of this structure but would also shed light on how this can be implemented in other such existing government office buildings in Bhubaneswar. The existing envelope has been documented and analyzed using U-Value calculations and simulation softwares like OPAQUE and Form it. A number of envelope retrofitting techniques have been studied and shortlisted through literature, desktop and case studies to propose the best strategies. It was found that 40% savings can be achieved by the retrofit strategy implemented. Also the live proposal of an extension of the existing block to accommodate a new division has been taken into consideration. An attempt has been made to design this block appropriately keeping in mind the required thermal performance standards.

Keywords: Building Envelope, Retrofitting, Thermal Performance, Insulation

1. THESIS PROPOSAL

1.1. Background

India is the 7th largest country in the world and home to over 1 billion people living across five different climatic zones. India is a rapidly growing economy with construction sector contributing to around 7.74% to the total GDP of the country. Commercial and residential development remains a priority for the construction industry due to its market potential/market demand/profit margins. These sectors also consume a large amount of energy over their life cycle, thus becoming one of the major sources of GHG emissions. Literature and current policy framework suggest that energy saving and its conservation is of prime importance to the government of India. The government is in a continuous process of suggesting and implementing policy frameworks to manage the energy usage from various sectors including the buildings sector. The government came out with a suggestive list of voluntary and mandatory programs and policies such as Energy Conservation Building Code (ECBC) for commercial buildings, Standards and Labelling

(S&L) program for appliances, Star rating program for existing building etc. to monitor and optimize the energy consumption from the sector.

1.2. Statement of problem

Retrofitting of building envelope to improve thermal performance refers to how well a building responds to the changes in external temperature during daily and seasonal cycles with respect to the building envelope (walls, roof, floor, windows, doors, skylights and other openings).

1.3. Aim of the paper

To Retrofit Existing old government office Building to improve the Thermal performance of the building to achieve thermal comfort

1.4. Objectives of thesis

- To study the principles of retrofitting technologies.
- To energy audit the existing govt. building and analyze current energy consumption.
- To find out different technologies and components of the building and ways to implement them.
- To formulate the application of retrofitting components to the building.
- To simulate and analyze the post retrofitting conditions and furnish final report.

1.5. Description of the project or the study area

1.5.1. Location and climatic zone classification

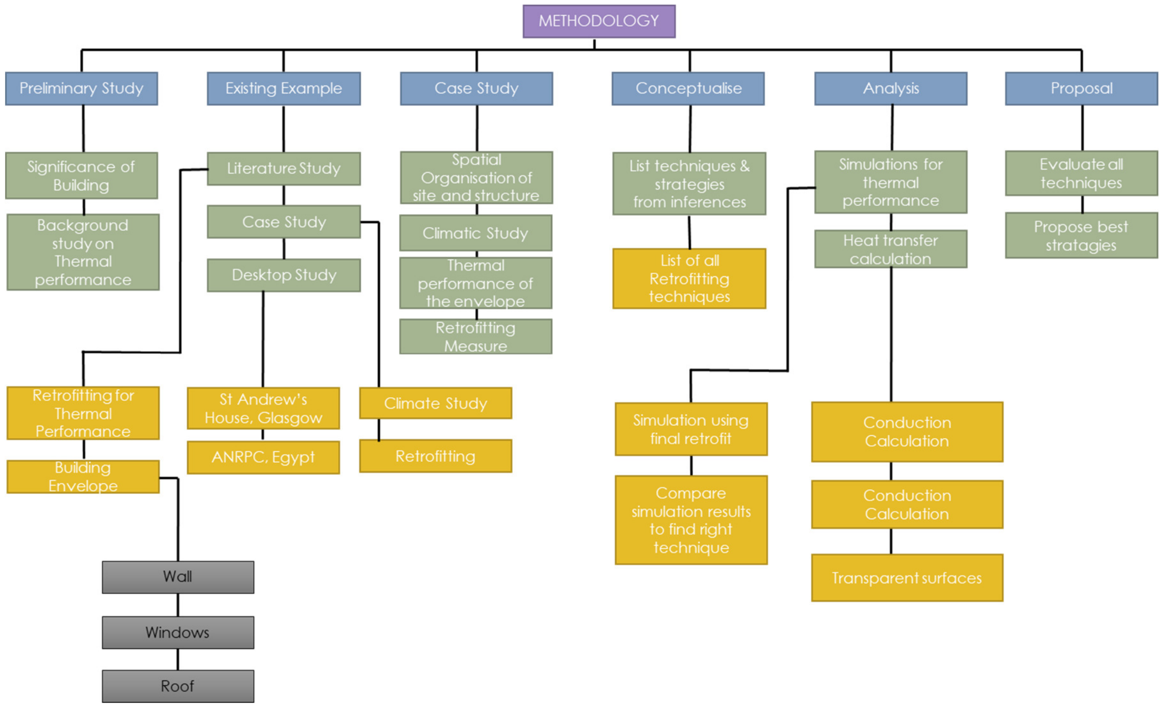
Figure 1 location of site

The office building is located in Bhubaneswar, Odisha. Secha Sadan (Water resources department) Bhubaneswar, Odisha was established in the year 1993.

1.5.2. Typology of the project or study area

Figure 2 Secha Sadan building

1.5.3. Proposed methodology



1.5.4. Limitation of the thesis

- Project is limited to providing thermal insulation to building envelope.
- There are some assumptions in the simulation modelling.
- For example, the data of internal gains from occupants, lighting and other appliances are taken from benchmarks and typical scenarios.
- The embodied energy is not simulated, which may be considered a limitation.

2. INTRODUCTION

A building once operational, continues to consume energy and increase its carbon footprint throughout its life. Retrofitting existing buildings can lead up to 15-20 % savings over the benchmark energy consumption. Retrofitting existing buildings to ensure energy efficiency and mitigate GHG emissions has been identified as one of the most effective mechanism by governments of various countries to reduce their energy consumption and mitigate GHG emissions.

In India major stock of office buildings was built before the implementation and access to modern energy saving technologies. According to the 17th EPS report published, it was estimated that electricity demand is estimated to increase by 37.5% by 2021-22 over a baseline of 2016-17. An ECBC Cell has been established in BDA to ensure energy efficiency in the buildings in the city through implementation of Odisha ECBC Code, 2011. A consultation meeting has been held to discuss and take feedback of all the major stakeholders vendor list has prepared who provide ECBC Compliant materials in state.

Studying the historical growth in consumption levels and population growth projections until the year 2018, it has been assessed that the energy consumption in Bhubaneswar in 2013 can be ascertained under the highest growth scenario as 1570.10 MU. The guidelines on “Retrofitting Existing commercial Buildings” presents a step by step approach to access the saving potential in the existing building and then stimulate implementable options and method to achieve required numbers in term of energy savings and GHG mitigation

3. LITERATURE REVIEW

3.1. Building Envelope

A building envelope is the physical separator between the conditioned and unconditioned environment of a building. The building envelope of a house consists of its roof, sub floor, exterior doors, and windows and of course the exterior walls. A building envelope is normally referred to as either 'tight' or 'loose'. A loose envelope allows air to flow more freely through the building, whereas a tight envelope restricts air or controls how it is admitted. From an energy efficiency point of view, the envelope design must take into consideration both the external and internal heat loads, as well as daylighting benefits. External loads include mainly solar heat gains through windows, heat losses across the envelope surfaces, and unwanted air infiltration in the building

3.2. Heat transfer in building

Heat transfer takes place through walls, windows, and roofs in buildings from higher temperature to lower temperature in three ways-conduction, convection, and radiation.

Table 1 Definition

	CONDUCTION	CONVECTION	RADIATION
DEFINITION	The transfer of heat through a solid material.	The transfer of heat by moving air	The transfer of heat In the form of electromagnetic waves

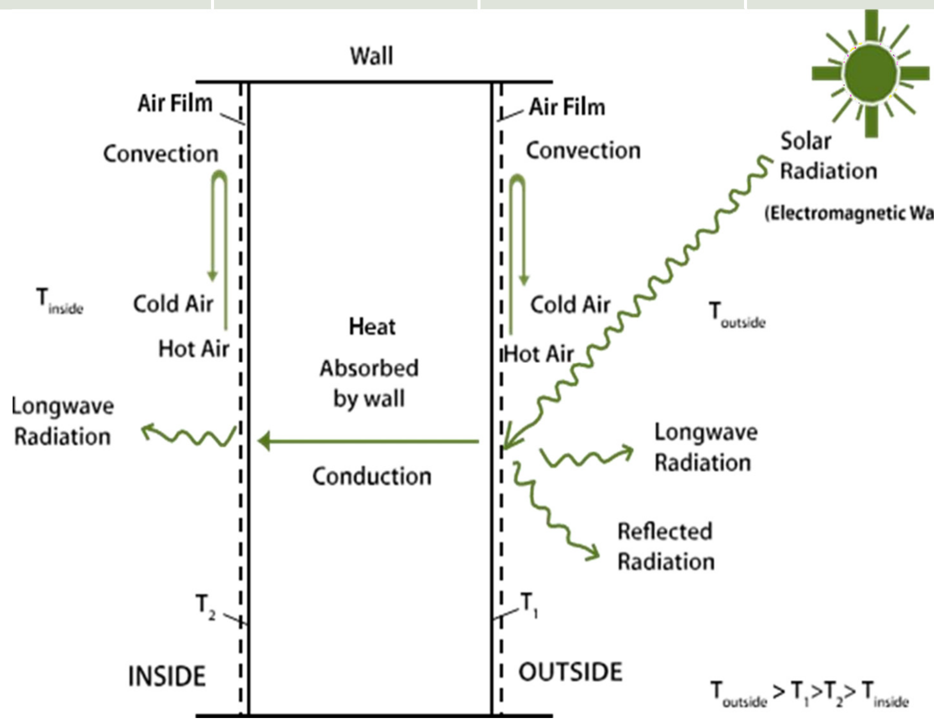


Figure 3 wall section showing heat transfer

3.3. Thermal properties

3.3.1. Thermal Conductivity of insulating materials

Thermal conductivity, also known as Lambda (λ), is the measure of how easily heat flows through a specific type of material, independent of the thickness of the material in question. The lower the thermal conductivity of a material, the better the thermal performance. It is measured in Watts per Meter Kelvin (W/mK).

3.3.2. R-Values

The R-value is a measure of resistance to heat flow through a given thickness of material. So the higher the R-value, the more thermal resistance the material has and therefore the better its insulating properties.

$$R = l / \lambda$$

Where:

l is the thickness of the material in meters and λ is the thermal conductivity in **W/mK**. The R-value is measured in meters squared Kelvin per Watt (m2K/W)

3.3.3. U-Values

The U value of a building element is the inverse of the total thermal resistance of that element. The U-value is a measure of how much heat is lost through a given thickness of a particular material, but includes the three major ways in which heat loss occurs – conduction, convection and radiation.

$$U = 1/[R_{si} + R_1 + R_2 + \ldots + R_{so}]$$

In practice this is a complicated calculation, so it is best to use U-Value calculation software.

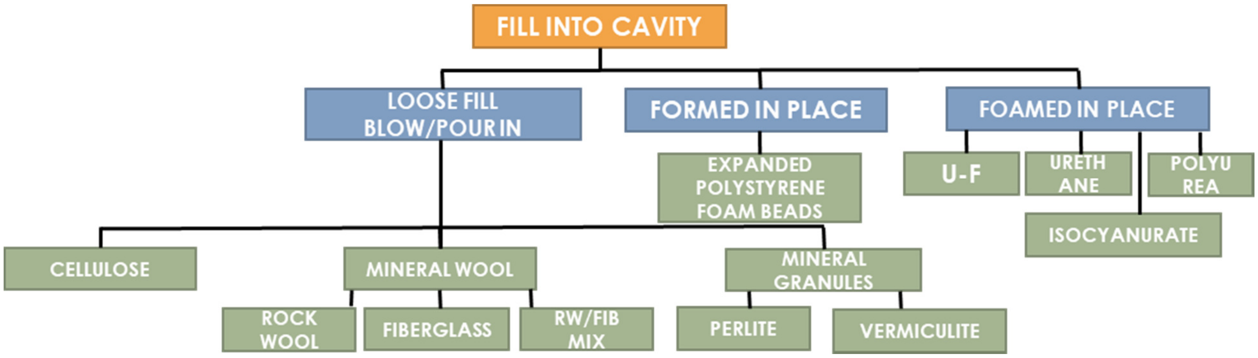
3.4. Retrofitting Envelope

3.4.1. Opaque Wall

Insulation of walls is also important for reducing conduction losses especially where significant difference exist between inside and outside temperature. Many insulation materials require an Air Barrier and Weather Resistive Barrier to prevent air and moisture movement into and out of the conditioned space, as well as for maintaining their installed R-value. Opaque Wall Assembly U-Factor and Insulation R-value Requirements (ECBC Table4.2).

Climate Zone	Hospitals, Hotels, Call Centers (24-Hour)		Other Building Types (Daytime)	
	Maximum U-factor of the overall assembly ($W/m^2 \cdot K$)	Minimum R-value of insulation alone ($m^2 \cdot K/W$)	Maximum U-factor of the overall assembly ($W/m^2 \cdot K$)	Minimum R-value of insulation alone ($m^2 \cdot K/W$)
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 opaque wall assembly recommendation



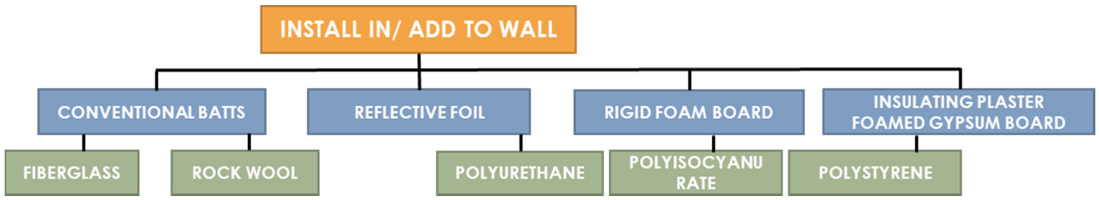


Table 3 recommended materials by IGBC

Material	U-value (W/m^2K)	Thickness (mm)
Extruded Polystyrene (XPS)	0.028	60
Glass Wool stuffing	0.25	150
Expanded Polystyrene (EPS)	0.30	100
Air (Still)	0.20	30

3.4.2. Roof

Roof can be insulated either over the deck or under the deck. Generally, over deck insulation is preferred, so as to avoid the absorption and retention of heat by the concrete surface. Under deck insulation can also be considered but the thickness of insulation should be higher.

Table 4 Recommendation 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/m ·K)	Minimum R-value of insulation alone (m ·K/W)	Maximum U-factor of the overall assembly (W/m ·K)	Minimum R-value of insulation alone (m ·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

3.4.3. Fenestration

Most large commercial buildings are dominated by cooling loads, so window selection for commercial buildings is usually an exercise in maximizing daylighting and keeping summer heat out. Today's best windows block heat transfer more than five times better than single-pane glass, the standard windows of just two decades ago. High-performance windows are not only a wise investment for new construction, but sometimes can be cost-effectively retrofitted, especially when timed with planned replacement and downsizing of HVAC equipment. Glazing products (windows, skylights, etc.) can be specified to reduce solar heat gain and control light levels and glare. As a rule of thumb, double glazing should always be preferred over single glazing since facades with double glazing not only offers superior thermal performance but can also help in significantly reducing unwanted external noise of traffic.

Windows are affected by many factors, which in turn affect the comfort and energy performance of buildings. Understanding these factors is critical to designing buildings that meet the needs of building owners and users. Once these factors are identified, a designer can then apply the appropriate technology to address them.

Table 5 Fenestration global recommendation

Most Efficient 2019 www.energystar.gov

Southern Zone Required Properties (mostly cooling)			
U-factor	Solar Heat Gain Coefficient (SHGC)	Visible Transmittance (VT)	Air Leakage (AL)
Windows: U≤0.40 Skylights: U≤0.60 *EWC Recommendation:* A low U-factor is useful during cold days when heating is needed. A low U-factor is also helpful during hot days when it is important to keep the heat out, but it is less important than SHGC in warm climates.	Windows: SHGC≤0.25 Skylights: SHGC≤0.28 *EWC Recommendation:* A low SHGC is the most important window property in warm climates. For superior energy performance, use windows with a SHGC of 0.25 or less.	Windows: VT=No Requirement Skylights: VT=No Requirement *EWC Recommendation:* Select windows with a higher VT to maximize daylight and view.	Windows: AL≤0.30 Skylights: AL≤0.30 *EWC Recommendation:* Select windows with an AL of 0.30 or less.

3.5. Insulation Strategies

Table 6 minimum U value for wall and roof

Climatic zones	24-Hour use buildings (Hospitals, Hotels, Call Centers etc.)		Daytime use buildings (Other Building Types)	
Composite, Hot & Dry and Warm & Humid	Maximum U - factor of the overall assembly (W/m^2-°C)	Minimum R – value of insulation alone (m^2-°C/W)	Maximum U - factor of the overall assembly (W/ m^2-°C)	Minimum R - value of insulation alone (m^2-°C/W)
Roof Assembly	0.261	3.50	0.409	2.10
Wall Assembly	0.440	2.10	0.440	2.10

Table 7 measures for reduction of heat gain

Measures	Wall	Roof	Window
Minimize Conduction Losses	Use insulation with low U-factor	Use insulation with low U-factor	Use material with low U-factor
Minimize Convection Losses	Reduce air leakage using a continuous air barrier system	Reduce air leakage using a continuous air barrier system	Use prefabricated windows and seal the joints between windows and wall
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 vapor barrier/retarder*	Watertight Airtight: continuous air barrier Use vapor barrier/ retarder*	Use prefabricated windows and seal the joints between windows and walls
Minimize Radiation Losses	Use light colored coating with high reflectance	Use light colored coating with high reflectance	Use glazing with low Solar Heat Gain Coefficient (SHGC); Use shading devices
* See the discussion about where to place a vapor barrier/retarder. (Fig. 7)			

Form	Method of Installation	Where Applicable	Advantages
Blankets: Batts or Rolls, Fiberglass, Rock wool	• Fitted between studs, joists and beams. Insulation must be protected by an air barrier membrane in order to maintain the installed R-value (conductive loops & wind washing) • The air barrier can be installed over exterior and/or interior sheathing and must be continuous	• Unfinished walls, floors and ceilings	• Easy installation, suited for standard stud and joist spacing, which is relatively free from obstructions
Loose-Fill: Spray-applied Rock wool, Fiberglass, Cellulose Polyurethane foam	• Blown into place or spray applied by special equipment Insulation must be protected by an air barrier membrane in order to maintain the installed R-value (conductive loops & wind washing) • The air barrier can be installed over exterior and/or interior sheathing and must be continuous	• Enclosed existing wall cavities or open new wall cavities • Unfinished attic floors and hard to reach places	• Commonly used insulation for retrofits (adding insulation to existing finished areas) • Good for irregularly shaped areas and around obstructions
Rigid Insulation: Extruded polystyrene foam (XPS), Expanded polystyrene Foam (EPS or Beadboard), Polyurethane foam, Polyisocyanurate foam	• Interior applications: Must be covered with 1/2-inch gypsum board or other building-code approved material for fire safety • Exterior applications: Must be covered with weather-proof facing or continuous Air and Weather Resistive Barrier (WRB)	• Basement walls, Exterior walls under finishing (Some foam boards include a foil facing which will act as a vapor retarder. Additionally, some insulation materials- e.g. XPS and closed cells polyurethane foams–are vapor retarders. Please read the discussion about where to place, or not to place a vapor retarder) • Unvented low slope roofs	• High insulating value for relatively little thickness • Can block thermal short circuits when installed continuously over frames or joists
Reflective Systems: Foil-faced paper, Foil-faced polyethylene bubbles, Foil-faced plastic film, Foil-faced cardboard	• Foils, films, or papers: Fitted between wood-frame studs joists, and beams	• Unfinished ceilings, walls, and floors (for wall applications, must consider that most foil faced systems act as a vapor retarder)	• Easy installation: All suitable for framing at standard spacing • Bubble-form suitable if framing is irregular or if obstructions are present

4. DESKTOP STUDY

4.1. Alexandria National Refining & Petrochemicals Co.(ANRPC)

Alexandria National Refining & Petrochemicals Co. (ANRPC) is a refinery based **office building** in **El-Max, Alexandria, Egypt**. The company has an administrative building. It was designed in 1995 and construction in 2000 finished.

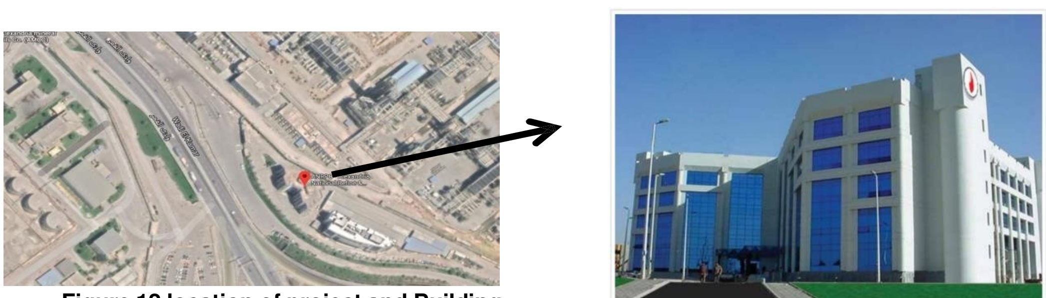


Figure 12 location of project and Building

4.1.1. Building typology

Office Building

Floors	Functions
Ground floor	Meeting Room – Reception
1st floor	Chairman + Managerial Board
2nd floor	Engineering Departments
3rd floor	Human Resources Departments
4th floor	Financial Departments

Total construction area of 3370 Sq.m.
22% reduction in both energy consumptions and Carbon emissions.

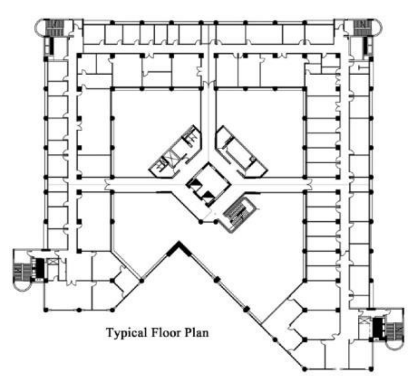


Figure 13 plan

4.1.2. Energy Data for the building

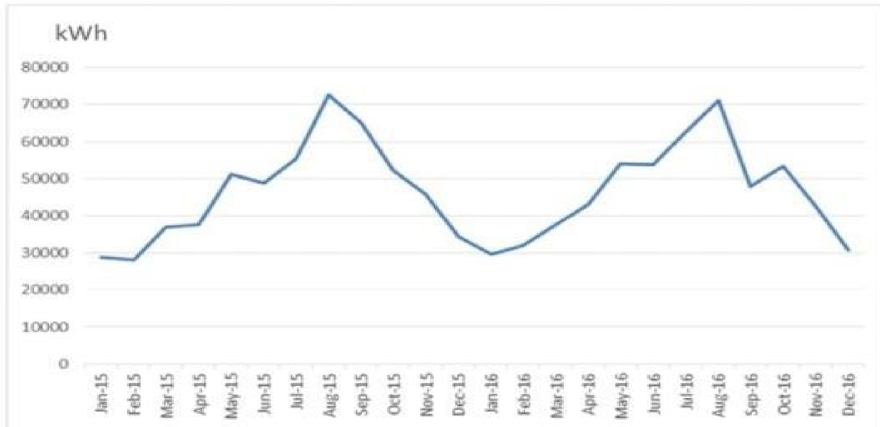
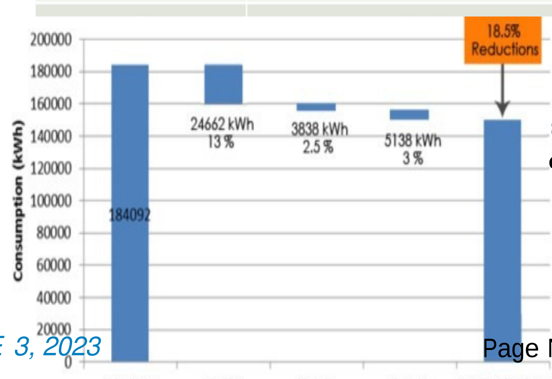


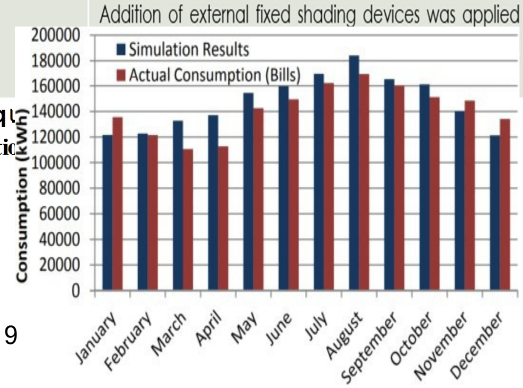
Figure 14 Electricity consumption pattern

ELEMENTS	DESCRIPTION
Ventilation	The building uses mechanical ventilation
Building Dimension	60m x 67m and height 20m
Exterior Shading	unshaded externally with large area of fixed curtain walls
Glazing	Tinted blue double glazed curtain walls **u-value = 2.7 W/m2 K**
WWR	All elevations = 80% ,north and north west elevations = 90%
Exterior walls	not insulated, 20cm brick wall, 2cm interior and exterior paint , u-value of 1.5 W/m2K.
Unshaded windows area	north-east elevation is 880 Sq.m, the north-west is 1098 Sq.m ,the south-west is 1072 Sq.m and the south-east is 960 Sq.m.
Roof	3130 Sq.m roof assembly consists of 20cm reinforced concrete roof, interior paint and insulation material having a u-value of 0.5 W/m2K

Table 8. Strategy Used

CASES	AREA OF RETROFIT	TECHNIQUE APPLIED
A	**WWR** adjustments(to accommodate the requirements of the Egyptian code for improvement of energy efficiency)	WWR **changed to 30%** for all elevations except for the north elevation which was kept as it is.
B	Thermal characteristics of the building envelope	improved its u-value by addition of 20cm insulation to external walls, also glazing was changed to triple glazed clear with argon fill instead of blue double glazing with air fill as well as green roof.
		Addition of external fixed shading devices was applied





5. CASE STUDY

5.1. Vastukar design studio, Bhubaneswar

5.1.1. Building Location

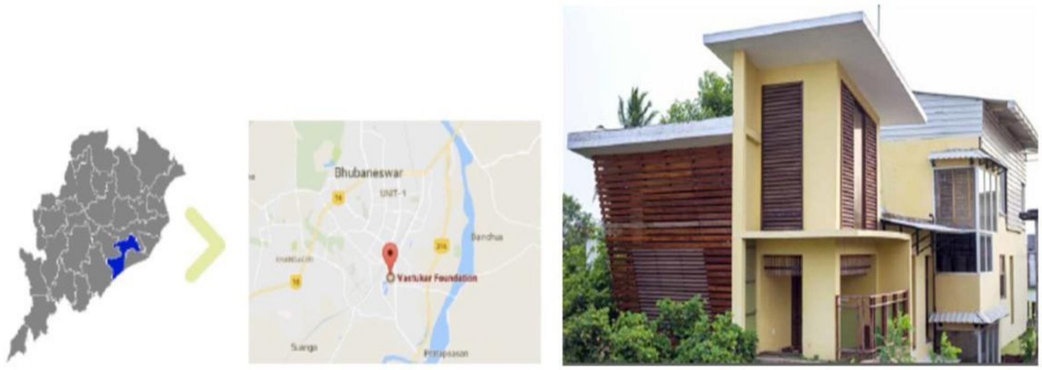


Figure 17 Building Location

5.1.2. Building Basics

Location	Bhubaneswar, Odisha
Climate Zone	Warm and Humid
Site Area	308 Sq.m.
Built-up Area	453 Sq.m. (48% of plot area)
Coordinates	20.2482° N, 85.8378° E
Number of Floors	2 Floors
Building Use	Office space
Constructed	2015
Certified	2016
Building Owner	Ar. S.S. Ray, director, Vastukar
Certification	SVA Griha rating- 5 star (47/50)

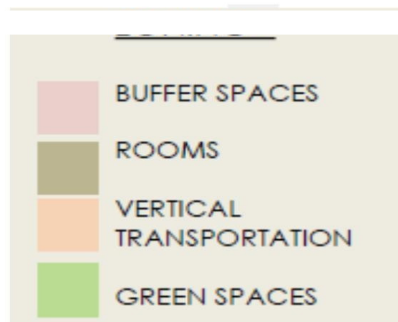
5.1.3. Building Strategy

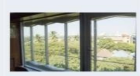
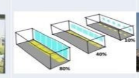
Table 12 Comparative Analysis

EAST FACADE	WEST FACADE	NORTH FACADE	SOUTH FACADE
			
Wall area exposed to the solar radiation is 17.6m²	Wall area exposed to the solar radiation is 48.2m².	Wall area exposed to the solar radiation is 17.6m².	Wall area exposed to the solar radiation is 150m².
WWR 26% which is less than 40% allows less amount of light penetrating through fenestrations.	WWR 15% which is less than 40% allows less amount of light penetrating through fenestrations.	WWR 65% which is more than 40% allows ample amount of light penetrating through fenestrations.	WWR 15% which is less than 40% allows less amount of light penetrating through fenestrations.
Wall thermal conductivity (K) 0.17 W/m k	Wall thermal conductivity (K) 0.40 W/m k	Wall thermal conductivity (K) 0.48 W/m k	Wall thermal conductivity (K) 0.40 W/m k
Wooden cladding over the glass opening is used to penetrate the radiation in to the room. Awing shading devices are suitable for all orientations. It is effective solar shading but reduce the daylight in summer and gain heat in winter.	There is no opening in the conference hall in the ground floor towards west side.	Appropriate design of openings and shading devices help to keep out sun and wind or allow them into the building. Ventilation lets in the fresh air and exhausts hot room air, resulting in cooling.	The size of windows are less compared to other sides decrease radiation

Figure 18 ground floor plan

Figure 19 First floor plan



	FACADE				FENESTRATION		ROOF
	NORTH	SOUTH	EAST	WEST	WINDOW GLAZING	W.W.R.	COOL ROOF
CASE STUDY 1 GODREJ BHAVAN, MUMBAI							
	ALLUMINIUM CLADING	ALLUMINIUM CLADING	ALLUMINIUM CLADING	ALLUMINIUM CLADING	DOUBLE GLAZED	60%	Terrace garden
CASE STUDY 2 VASTUKAR DESIGN STUDIO, BHUBNESWAR							No garden in roof
	iron hollow sections, creepers, plywood, buildtec sheet ,stone wall	Wooden louvers, stone wall	plywood, low voc paints, glass,	vertical green wall, glass,	Single Glazed, Wooden frame	26% EAST 15% WEST 65%NORTH 15% SOUTH	ALBIDO PAINT

5.1.4. SUMMARY

It was observed that facade on the south, east and west should be shaded by any shaded device and must be insulated properly to have a lower U value. Windows must be double glazed for good thermal performance and air leakage must be checked in air conditioned spaces. Green roof is better option as it gives a satisfactory decrease in surface temperature. Insulation can be applied to the exterior as the project is not of any heritage importance, which will also leave the internal space unharmed.

6. SITE ANALYSIS

6.1. Secha Sadan(Water Resources Department), Bhubaneswar

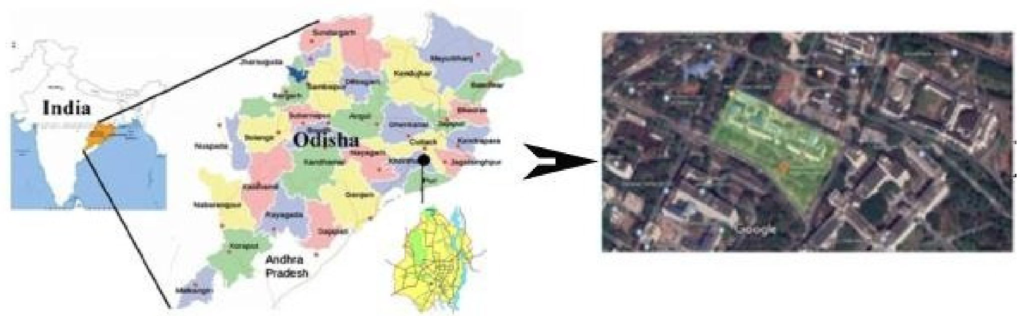


Figure 20 Location

6.2. Building Basics

SECHA SADAN
(WATER RESOURCES DEPARTMENT)
Bhubaneswar, Odisha
ESTD. 1993

Type- Institutional(office building)

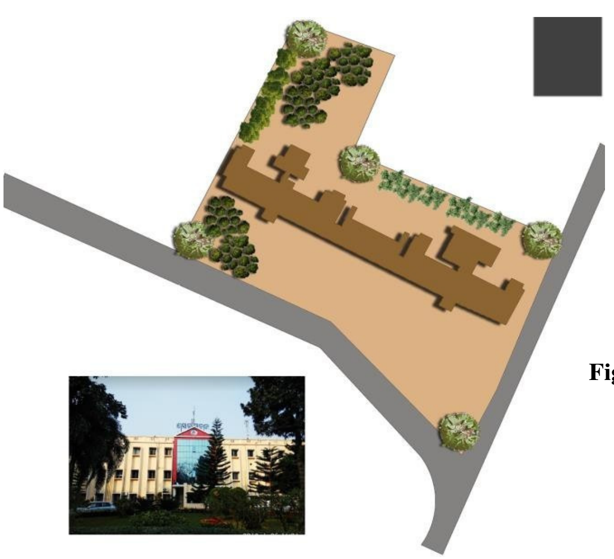
Total area- 3.5 Acres(approx.)

Built-up area- 12000 Sq.m (approx.)

No of floors- 3

No of rooms- Around 270

Figure 21 Building View



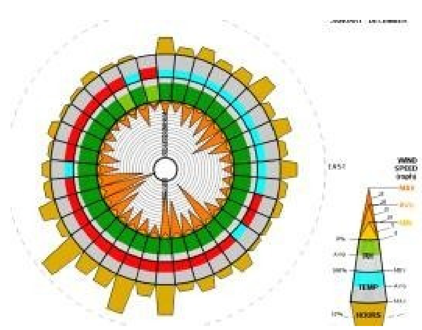


Figure 22 & 23 Existing Site & Wind Wheel

Figure 24. Site section AA

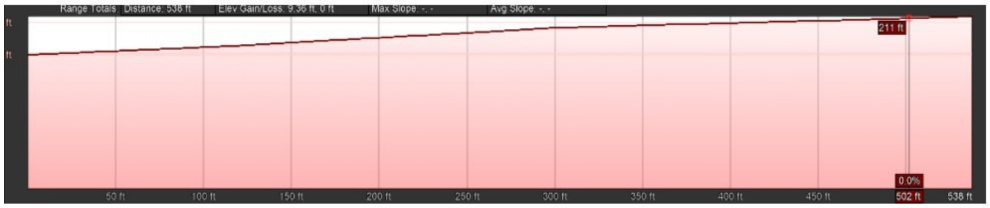


Figure 25. Site section AA

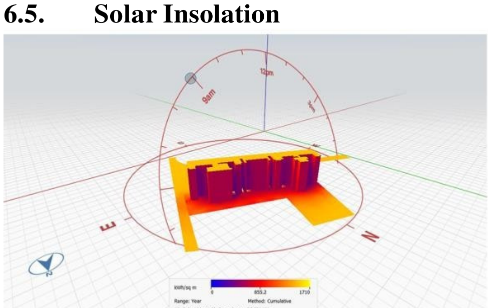
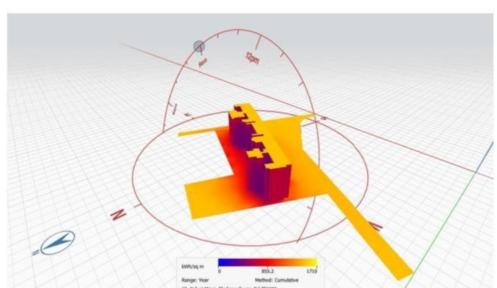
6.3. Site proximity

Figure 26 Proximity

6.4. Problems

- The South side of the office gets heated up which brings uncomfortable situations.
- The air conditioners are split and window type and they demand a lot of maintenance.
- Not much daylight enters into the building and current lights are not energy efficient.
- Uncontrolled thermal performance.
- Building is installed with older technology hence does not fit the energy saving compliance

6.5. Solar Insolation

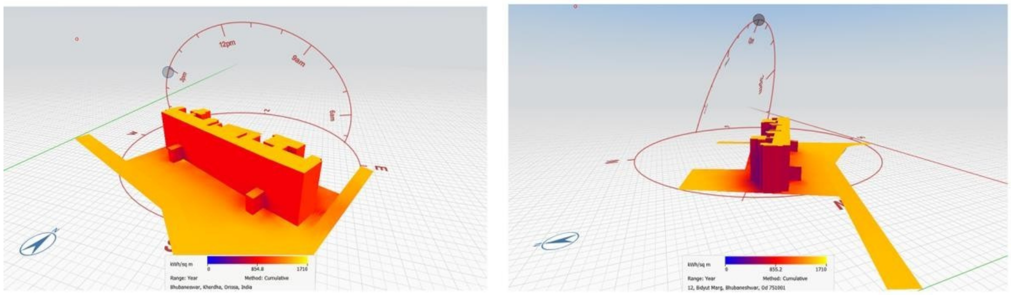


Figure 27 Insolation simulation

South-West Facade receives maximum insolation in year cumulative, followed by NW, SE and in the last NE. South-West Facade being the longest and front facade needs Envelope Retrofitting to increase thermal performance of the building.

6.6. Shadow analysis

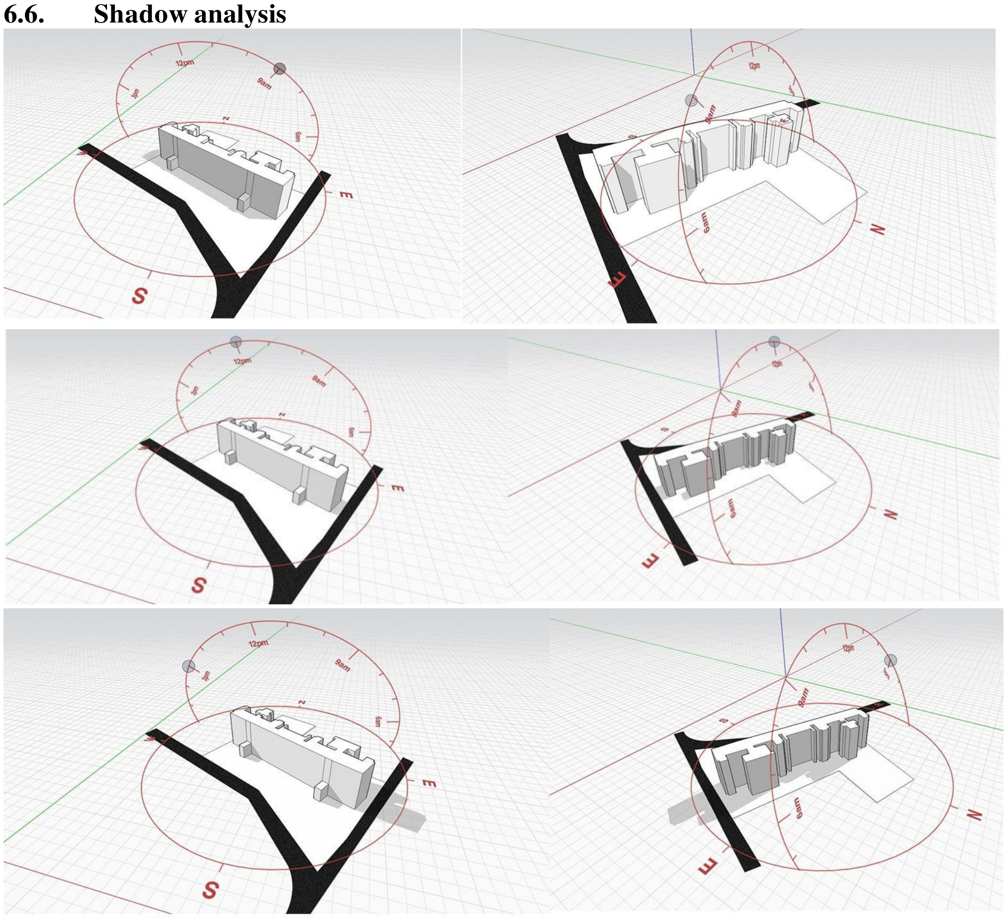
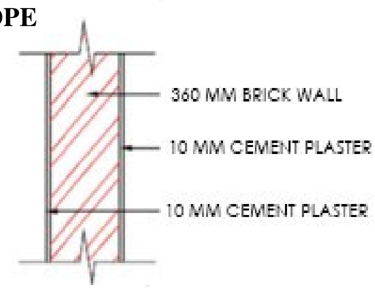


Figure 28 Shadow Analysis

7. THERMAL PERFORMANCE OF THE ENVELOPE

7.1. Wall



L 1 = 0.01M, K 1 = 0.721 W/M.K L 2 = 0.36M,
K 2 = 0.811 W/M.K, L 3 = 0.01M, K 3 = 0.721 W/M.K,
hI = 8.3 W/M2.K, hO = 22.7 W/M2.K,
RT = 1/8.3 + 0.01/0.721 + 0.36/0.811 + 0.01/0.721 + 1/22.7 =0.636, U = 1/ RT =1/0.636 = 1.57

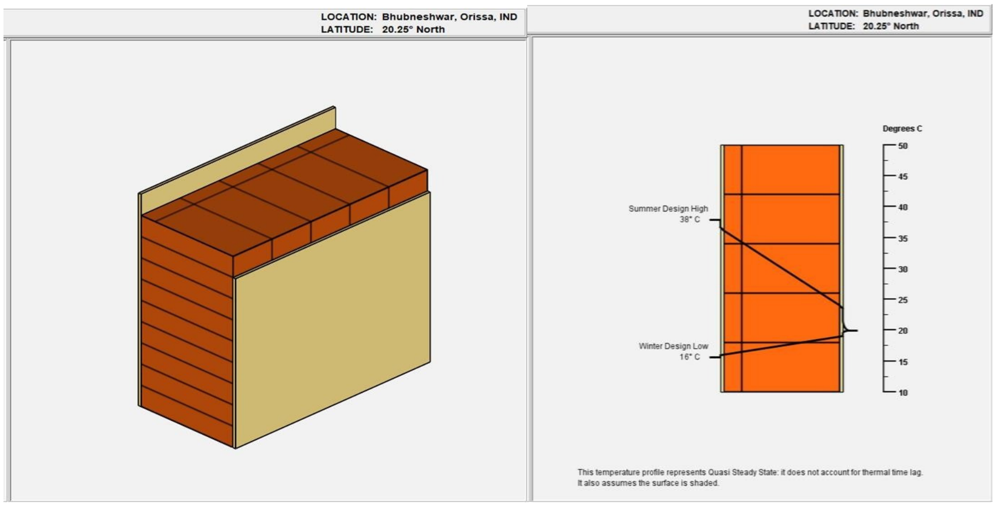


Figure 29 wall cut view and wall section

7.2. Roof

L 1 = 0.01M, K 1 = 0.721 W/M.K L 2 = 0.15M, K 2 =1.580 W/M.K L 3 = 0.01M,
K 3 = 0.721 W/M. hI = 6.1 W/M2.K, hO = 22.7 W/M2.K
RT = 1/6.1 + 0.01/0.721 + 0.15/1.580 + 0.01/0.721 + 1/22.7=0.331
U = 1/ RT =1/0.331 = 3.02

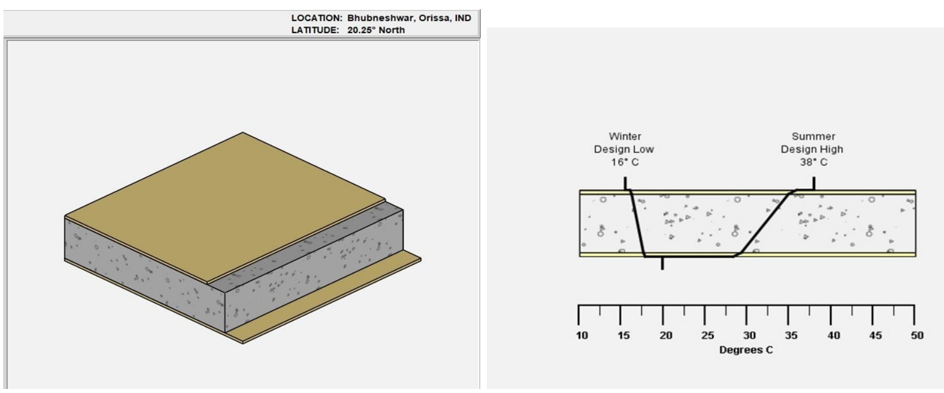


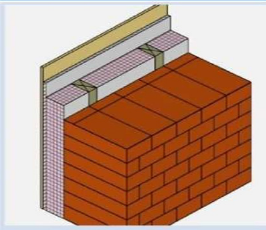
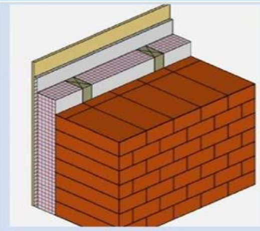
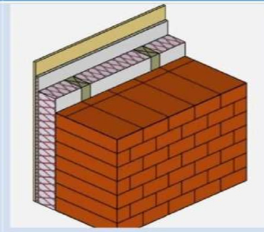
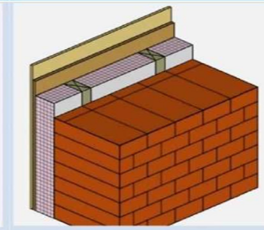
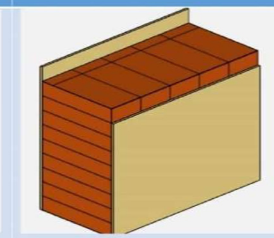
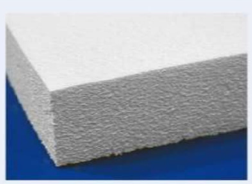
Figure 30 Roof cut view and section

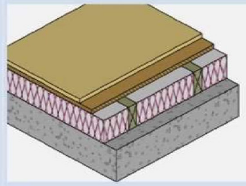
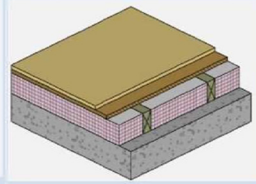
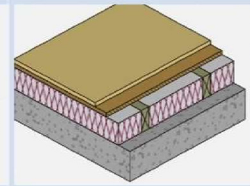
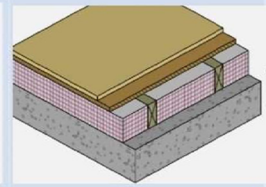
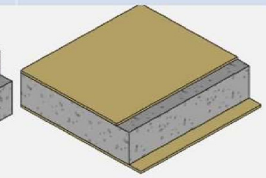
7.3. Fenestration

Uncoated single-glazed windows are considered to be the weakest thermal component in the building envelope, transmitting large amounts of heat into and out of a building.

Figure 31 Window

7.4. Comparative analysis

	CASE 1	CASE 2	CASE 3	CASE 4	BASE CASE
3D SECTION					
MATERIALS	Material / mm / R Value Inside Air Film (wall) 0.0 0.12 Brick 360.0 0.4 Studs (wood) 101.6 0.78 Expanded Polystyrene (EPS) 101.6 2.54 Gypsum Board 15.9 0.1 Plaster (dense) 12.7 0.02 Outside Air Film 0.0 0.04	Material / mm / R Value Inside Air Film (wall) 0.0 0.12 Brick 360.0 0.4 Studs (wood) 101.6 0.78 Polyurethane Foam 101.6 4.06 Plaster Board 16.0 0.03 Plaster (dense) 12.7 0.02 Outside Air Film 0.0 0.04	Material / mm / R ... Inside Air Film (wall) 0.0 0.12 Brick 360.0 0.4 Studs (wood) 101.6 0.78 Blown Fibre 101.6 2.54 Gypsum Board 15.9 0.1 Plaster (dense) 12.7 0.02 Outside Air Film 0.0 0.04	Material / mm / R ... Inside Air Film (wall) 0.0 0.12 Brick 360.0 0.4 Studs (wood) 101.6 0.78 Batt Insulation 101.6 2.03 Plywood 15.9 0.13 Plaster (dense) 12.7 0.02 Outside Air Film 0.0 0.04	Material / mm / R ... Plaster (dense) 10.0 0.02 Brick 360.0 0.4 Plaster (dense) 10.0 0.02 Outside Air Film 0.0 0.04
SIMULATION RESULTS	Total Thickness (mm): 490.2 Total R Value: 2.48 Total U Value: 0.403 Decrement Factor: 0.06 Time Lag: 10.0	Total Thickness (mm): 490.3 Total R Value: 2.95 Total U Value: 0.339 Decrement Factor: 0.06 Time Lag: 9.58	Total Thickness (mm): 490.2 Total R Value: 2.48 Total U Value: 0.403 Decrement Factor: 0.06 Time Lag: 10.09	Total Thickness (mm): 490.2 Total R Value: 2.28 Total U Value: 0.439 Decrement Factor: 0.06 Time Lag: 10.14	Total Thickness (mm): 380.0 Total R Value: 0.48 Total U Value: 2.085 Decrement Factor: 0.34 Time Lag: -9.47
ECBC REQUIREMENT	Maximum assembly U value = 0.40	Maximum assembly U value = 0.40	Maximum assembly U value = 0.40	Maximum assembly U value = 0.40	Maximum assembly U value = 0.40
COMPLIANCE	NO	YES	YES	NO	NO
INSULATION					NO

	CASE 1	CASE 2	CASE 3	CASE 4	BASE CASE
3D SECTION					
MATERIALS	Material / mm / R ... Inside Air Film (ceiling) 0.0 0.16 Concrete 150.0 0.11 Studs (wood) 110.0 0.85 Insulation Board 110.0 3.67 Fiberboard Sheathing 20.0 0.29 Plaster (dense) 20.0 0.04 Outside Air Film 0.0 0.04	Material / mm / R ... Inside Air Film (ceiling) 0.0 0.16 Concrete 150.0 0.11 Studs (wood) 110.0 0.85 Polyurethane Foam 110.0 4.4 Fiberboard Sheathing 20.0 0.29 Plaster (dense) 20.0 0.04 Outside Air Film 0.0 0.04	Material / mm / R ... Inside Air Film (ceiling) 0.0 0.16 Concrete 150.0 0.11 Studs (wood) 110.0 0.85 Blown Fibre 110.0 2.75 Fiberboard Sheathing 20.0 0.29 Plaster (dense) 20.0 0.04 Outside Air Film 0.0 0.04	Material / mm / R ... Inside Air Film (ceiling) 0.0 0.16 Concrete 150.0 0.11 Studs (wood) 110.0 0.85 Batt Insulation 110.0 2.2 Fiberboard Sheathing 20.0 0.29 Plaster (dense) 20.0 0.04 Outside Air Film 0.0 0.04	Material / mm / R ... Inside Air Film (ceiling) 0.0 0.16 Plaster (dense) 10.0 0.02 Concrete 150.0 0.11 Plaster (dense) 10.0 0.02 Outside Air Film 0.0 0.04
SIMULATION RESULTS	Total Thickness (mm): 300.0 Total R Value: 3.6 Total U Value: 0.277 Decrement Factor: 0.21 Time Lag: -8.67	Total Thickness (mm): 300.0 Total R Value: 4.05 Total U Value: 0.247 Decrement Factor: 0.21 Time Lag: -8.62	Total Thickness (mm): 300.0 Total R Value: 2.99 Total U Value: 0.334 Decrement Factor: 0.22 Time Lag: -7.84	Total Thickness (mm): 300.0 Total R Value: 2.59 Total U Value: 0.386 Decrement Factor: 0.22 Time Lag: -7.86	Total Thickness (mm): 170.0 Total R Value: 0.34 Total U Value: 2.922 Decrement Factor: 0.58 Time Lag: -4.99
ECBC REQUIREMENT	Maximum assembly U value = 0.33	Maximum assembly U value = 0.33	Maximum assembly U value = 0.33	Maximum assembly U value = 0.33	Maximum assembly U value = 0.33
COMPLIANCE	YES	YES	YES	NO	NO
INSULATION					NO

	CASE 1	CASE 2	CASE 3	CASE 4	BASE CASE
3D SECTION					
NAME	Double-Glazed, Clear Glass	Double-Glazed, Low-solar-gain Low-E Glass	Triple-Glazed, High-solar-gain Low-E Glass	Triple-Glazed, Low-solar-gain Low-E Glass	Single-Glazed, Clear Glass
PROPERTY (METAL FRAME)	U VALUE- 0.71-0.99 SHGC- 0.41-0.55 VLT- >0.60	U VALUE- 0.56-0.70 SHGC- 0.25 VLT- 0.51	U VALUE- 0.21 SHGC- 0.41 VLT- 0.41	U VALUE- ≤0.22 SHGC- ≤0.25 VLT- ≤0.40	U VALUE- 1.04 SHGC- 0.86 VLT- 0.90
PROPERTY (NON METAL FRAME)	U VALUE- 0.41-0.55 SHGC- 0.41-0.60 VLT- >0.60	U VALUE- 0.23-0.30 SHGC- 0.25 VLT- 0.51	U VALUE- 0.19 SHGC- 0.41 VLT- 0.41	U VALUE- ≤0.21 SHGC- ≤0.25 VLT- ≤0.40	NA
U VALUE (ECBC)	Maximum U value 3.00	Maximum U value 3.00	Maximum U value 3.00	Maximum U value 3.00	Maximum U value 3.00
VLT(ECBC)	Minimum VLT= 0.27	Minimum VLT= 0.27	Minimum VLT= 0.27	Minimum VLT= 0.27	Minimum VLT= 0.27
SHGC(ECBC) Effective	Maximum SHGC Non north=0.27 North=0.50	Maximum SHGC Non north=0.27 North=0.50	Maximum SHGC Non north=0.27 North=0.50	Maximum SHGC Non north=0.27 North=0.50	Maximum SHGC Non north=0.27 North=0.50
COMPLIANCE	YES NORTH	YES NON NORTH	YES NORTH	YES NON NORTH	NO

8. STRATEGY ANALYSIS

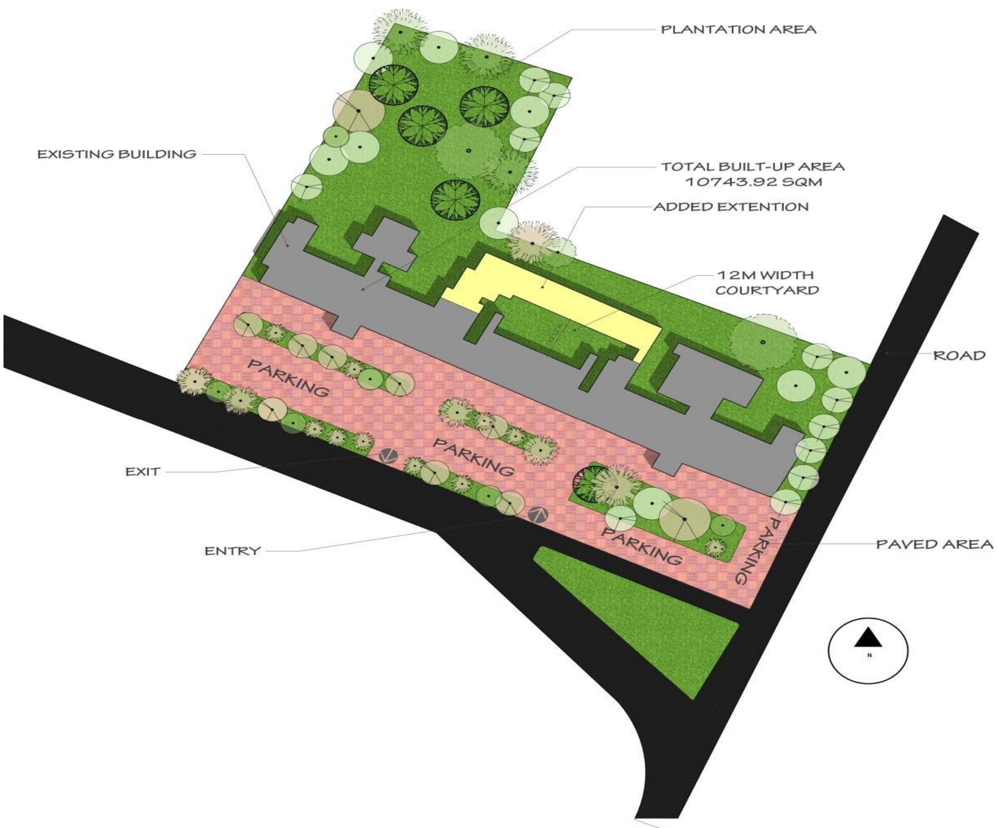
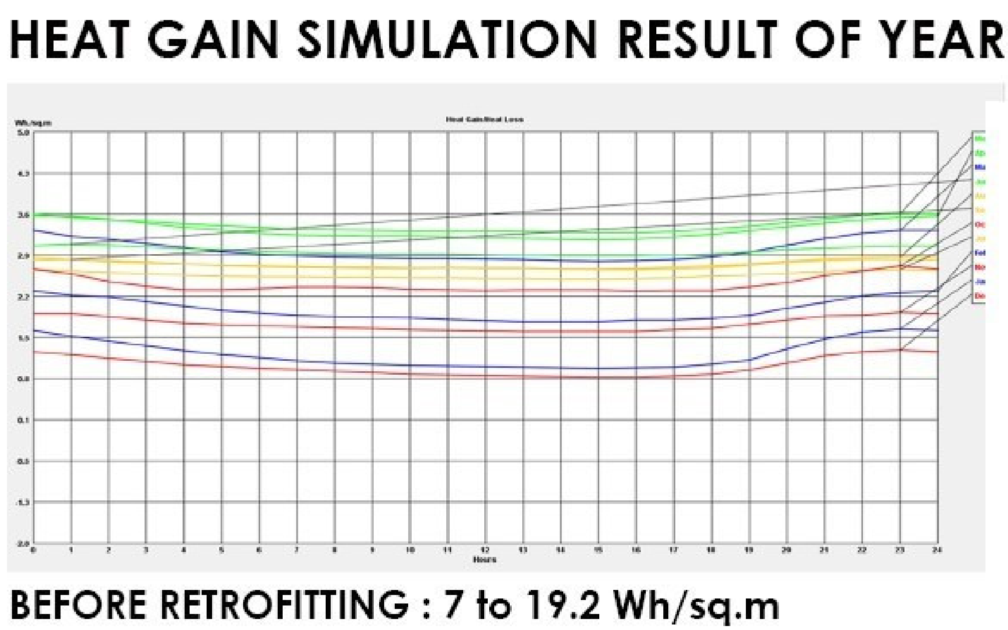
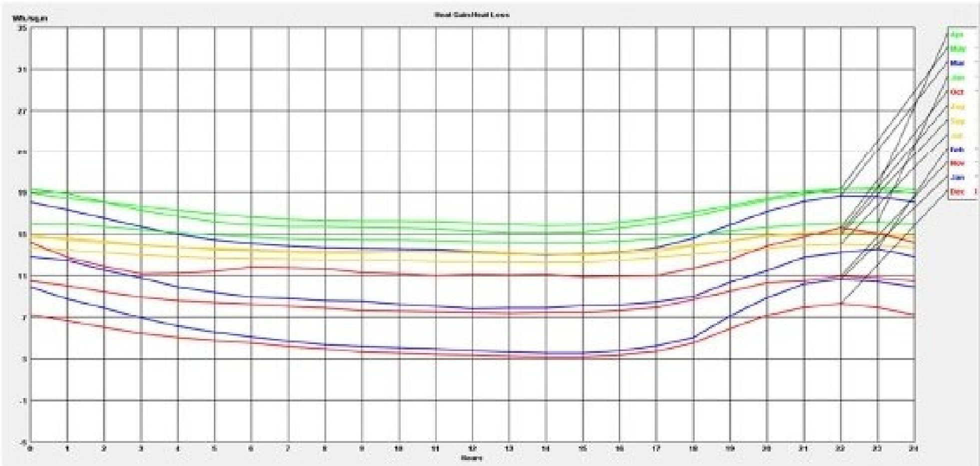


Figure 32. Site plan

9 RESULT

9.1 Heat Gain Simulations





AFTER RETROFITTING : 1 to 3.6 Wh/sq.m

EnEff:ResBuild India
Toolkit for energy efficient residential buildings in India

kfw teri Fraunhofer

Project:	Retrofitting for Energy Efficiency

Building:

Address of project:
Keshari Nagar, Bhubaneswar

Occupant/Owner:
Government of Odisha

Table of results - Electrical energy in kWh/m²yr*:

	This building	Reference building
Internal lighting	12.58	12.58
Common lighting	1.64	1.64
Parking lighting	0.00	0.00
Cooling	8.20	22.03
Heating	0.00	0.00
Hot water	11.29	11.29
Ceiling fans	0.72	0.72
Appliances	0.28	0.28

Building parameters:	
Building type:	Residential building
Total building area:	10,743.92 m²
Climatic zone:	Bhubaneshwar (Warm & Humid)
Created with:	EneffResBuild:India Version 1.0.1.0

Consumption of electrical energy in kWh/m²yr*:

*The consumption is related to the building area.

This building:
20 kWh/m²yr

0 5 10 15 20 25 30 35 40

Reference:
34 kWh/m²yr

Savings: 40%

Energy shares considered for the loan application certificate:
- [ ] Internal lighting
- [ ] Common lighting
- [ ] Parking lighting
- [x] Cooling
- [ ] Heating
- [x] Hot water
- [x] Ceiling fans
- [x] Appliances

Qualitative parameters (0 out of 6 measures are applied in this building):

☐ Daylit area in the core area is 20% to 40%	☐ Presence detection or photo sensors for outdoor and s
☐ Solar street lights	☐ Efficient water pumps
☐ Efficient transformers	☐ Tailored user manual

Issuer:

5/7/2020 .... () ....
Date Signature

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This paper and the research behind it would not have been possible without the exceptional support of my supervisor, Ar. Archana S. Her enthusiasm, knowledge and exacting attention to detail have been an inspiration and kept my work on track from my first encounter with the topic to the final draft of this paper. My colleagues in my university have also looked over my transcriptions and answered with unfailing patience numerous questions about the language. The generosity and expertise of one and all have improved this study in innumerable ways and saved me from many errors; those that inevitably remain are entirely my own responsibility.

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